Exploring the Estimation of Production Breaks Using EVM

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Goal of the Brief

This briefing explores using recurring manufacturing EVM data to help estimate the cost impact of production breaks.

Learning Objectives

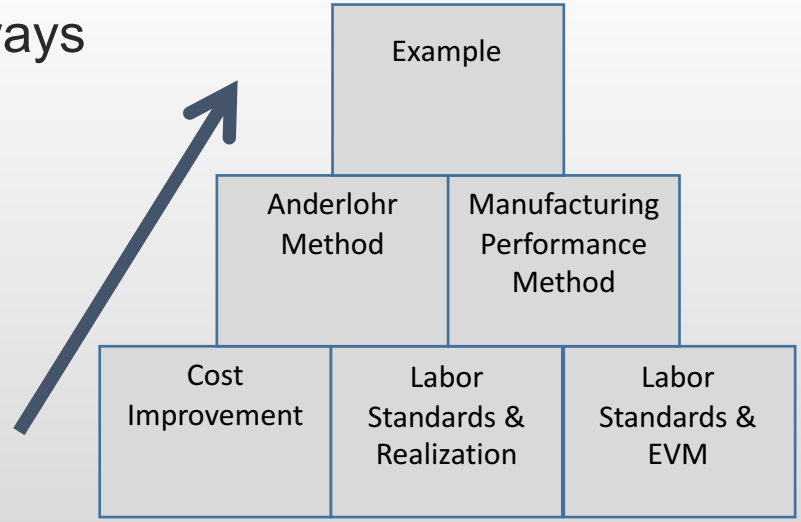
Understand concepts associated with estimating recurring manufacturing

Understand theoretical relationship between labor standards and EVM

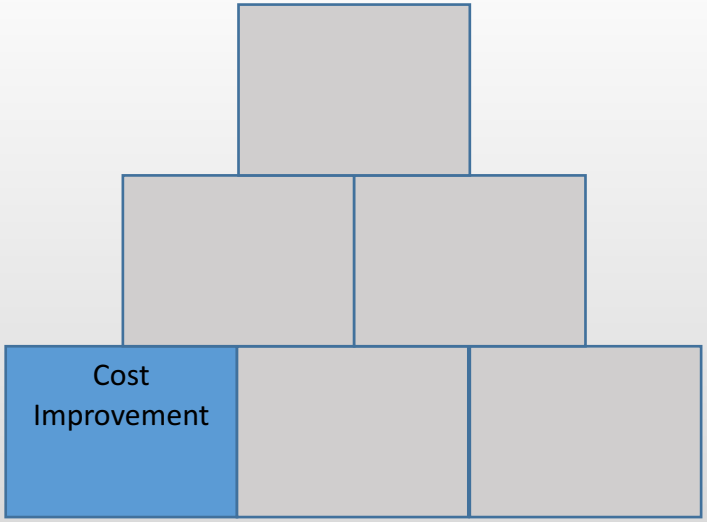
Understand concepts associated with estimating production breaks

Outline

- Cost Improvement Theory
- Labor Standards and Realization
- Labor Standards and EVM
- Anderlohr Method
- Manufacturing Performance Method
- Example
- Key Take-Aways



Cost Improvement Theory



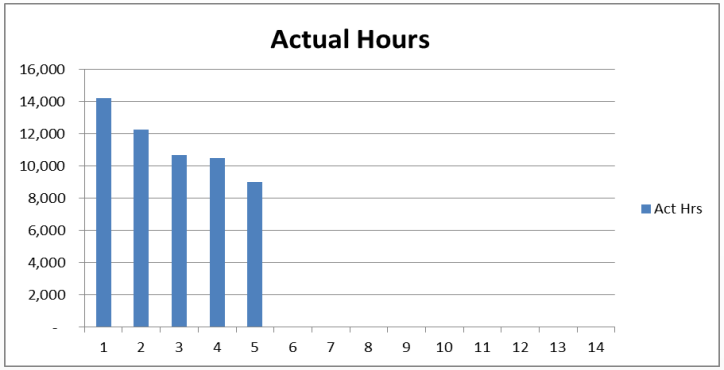
Concept of Cost Improvement

- Theory of Learning: a constant percentage of labor hour improvement occurs with every doubling of units produced
- Theory of Cost Improvement: a constant percentage of unit cost (or cum avg cost) improvement occurs with every doubling of units produced
  - Can be applied to hours or costs
  - Modeled mathematically as:
    - $A_x = T_1 * X^b$
    - Where
      - A_x= Cost of unit x
      - T_1 = Theoretical first unit cost
      - X = unit number at which you want to evaluate A
      - b = constant = ln (learning curve slope) / ln (2)

Cost Improvement Example

- Start with actual hours

Prod unit	Act Hrs
1	14,230
2	12,259
3	10,698
4	10,480
5	8,991



- Perform linear transformation of the data
  - $A_x = T_1 * X^b \Rightarrow \ln(A_x) = \ln(T_1) + b * \ln(X)$

- Use simple linear regression on transformed data to estimate learning curve (LC) parameters

Parameter	Estimate
T1	14,456
Slope	83.11%
b	-0.27

Cost Improvement Example

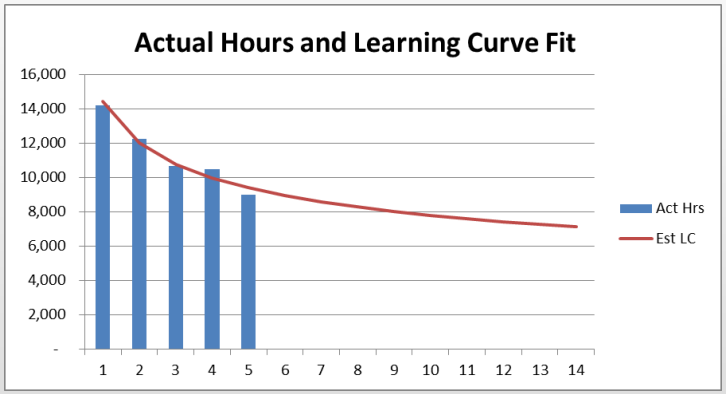
- Plug LC parameters into equation

Parameter	Estimate
T1	14,456
Slope	83.11%
b	-0.27

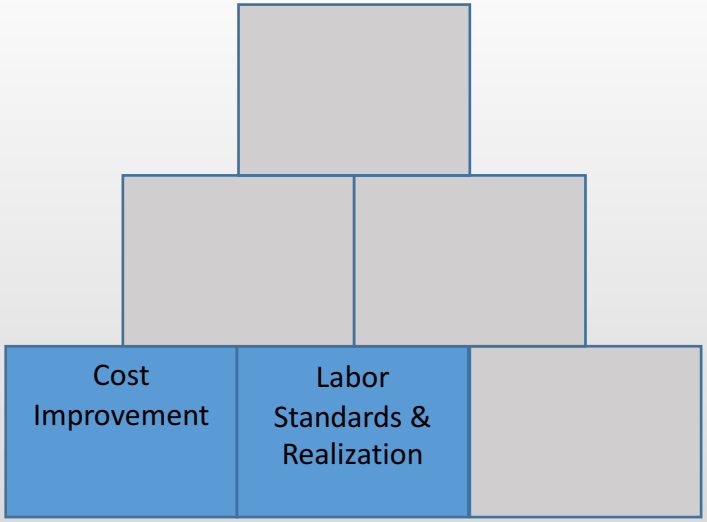
$$Ax=T_1*X^b$$

- Assess LC equation for each future unit ("X")

Prod unit	Act Hrs	Est LC
1	14,230	14,456
2	12,259	12,015
3	10,698	10,782
4	10,480	9,985
5	8,991	9,408
6		8,961
7		8,600
8		8,299
9		8,042
10		7,819
11		7,623
12		7,448
13		7,290
14		7,147



Labor Standards and Realization



Labor Standards

- A labor standard is a measure of the time it should take for a qualified worker to perform a particular operation
- Labor standards are commonly grouped into two types: Engineered and NonEngineered Standards
  - Engineered Standards:

Engineered standards are developed using recognized principles of industrial engineering and work measurement. The standards developed define the time necessary for a **qualified worker**, working at a **pace ordinarily used**, under **capable supervision**, and **experiencing normal fatigue and delays**, to do a defined amount of work of specified quality when following the **prescribed method**. As a result, you can use engineered standards to examine contractor operations to estimate the number of labor hours that should be required to efficiently and effectively produce a particular product and to identify any projected contractor variances from that estimate.

Text on slide from Contract Pricing Finance Guide http://www.acq.osd.mil/dpap/cpf/docs/contract_pricing_finance_guide/vol2_ch8.pdf

Labor Standards

- NonEngineered Standards:

Non-engineered standards are developed using the best information available without performing the detailed analysis required to develop engineered standards. Historical costs are commonly used standards that typically measure the hours that have been required to complete a task rather than the hours that should be required.

Text on slide from Contract Pricing Finance Guide http://www.acq.osd.mil/dpap/cpf/docs/contract_pricing_finance_guide/vol2_ch8.pdf

Underlying Assumptions

- **Theoretically, if assumptions hold true, actual hours = Labor Standards**
  - Qualified worker
    - Assumption can fail at start of production and with workforce turnover
  - Pace ordinarily used
    - Assumption can fail at start of production due to high levels of worker training; assumption can fail with workforce turnover
  - Under capable supervision
    - Assumption less sensitive to start of production and workforce turnover
  - Experiencing normal fatigue and delays
    - Assumption can fail with environmental impacts that impact workers and parts availability
  - Defined amount of work
    - Assumption can fail with design problems/supplier problems, unplanned parts removal and replacement
    - However, if work content changes systematically, planners will increase or decrease standards accordingly
  - Of a specified quality
    - This assumption shouldn't fail, since controls are in place to force the standard of quality; rather, the quality standard is a forcing function that could drive rework
  - Following the prescribed method
    - Assumption can fail at start of production, with workforce or supervisor turnover, due to quality issues or disruptions in the process requiring out-of-station work or rework

[Forward]

Realization Factor

- Production managers use labor standards to plan hours needed for each production lot
- When workers actually produce, there will be a difference between the labor standard hours and the actual hours
- Realization factors can be calculated and tracked as a performance metric

$$\frac{\text{Actuals}}{\text{Standards}} = \text{Realization Factor}$$

Improvement of “Process”

- Manufacturing labor standards at a given point in time represent the defined production process
- Industrial Engineers introduce efficiencies into the process over time
  - Examples: tooling improvements, manufacturing flow improvements, line balancing, automation, outsourcing to a more efficient producer
  - Improvements are reflected in a lowering of the labor standards as production progresses
  - The opportunities for process improvements diminish over time (improvement at a decreasing rate)

Labor Standards are measured in Standard Hours

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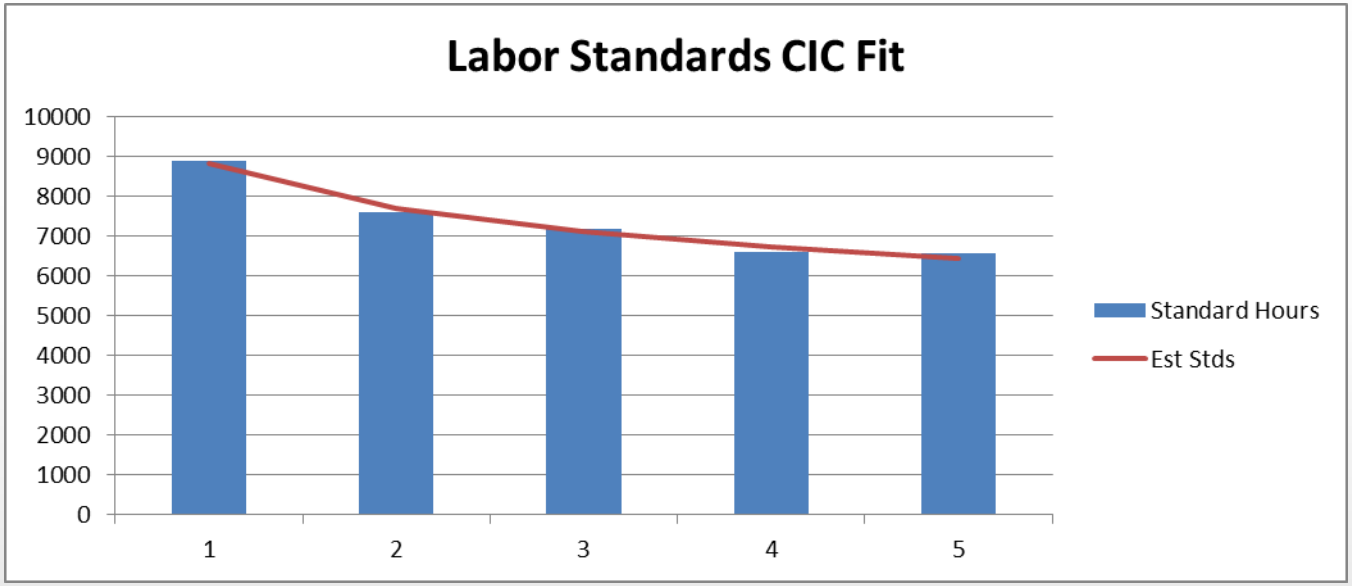
Labor Standards Cost Improvement



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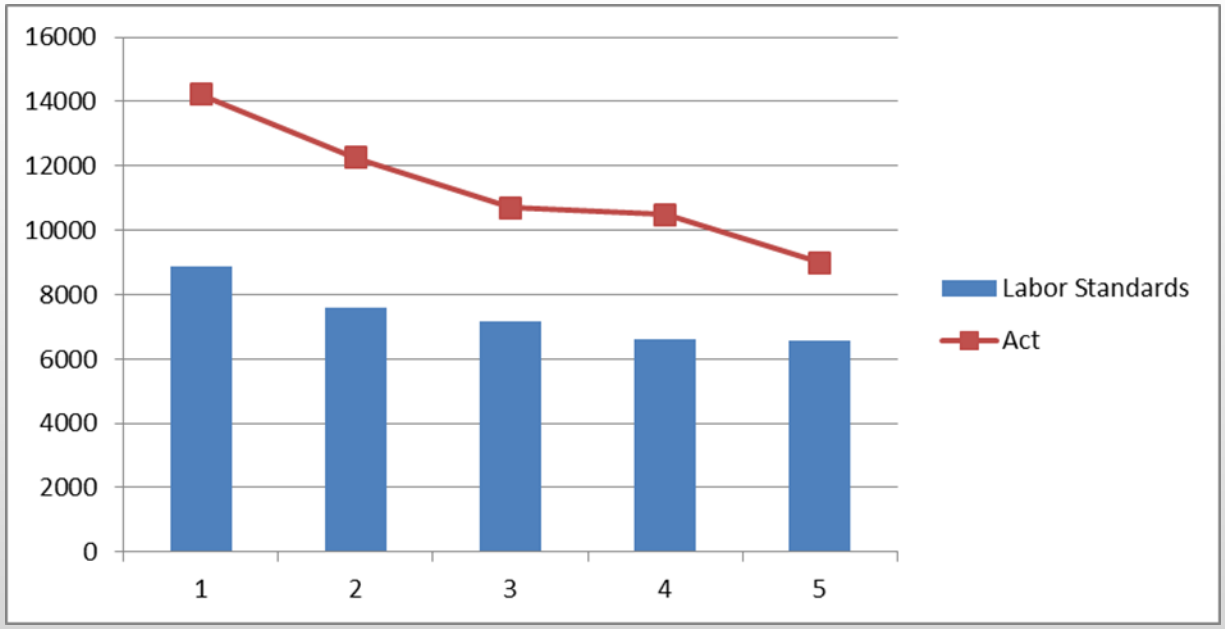
Actuals versus Standards

- Labor Standard assumptions represent an ideal, to be compared with reality
- Actual hours can be tracked and compared to the standards
- Standards are meant to be achievable and when actuals significantly deviate from standards, management investigates to find the root cause
  - Cause might not be a problem with the standards; it could be a management issue
  - Assembly lines are managed on standards; standards that are not achievable are changed



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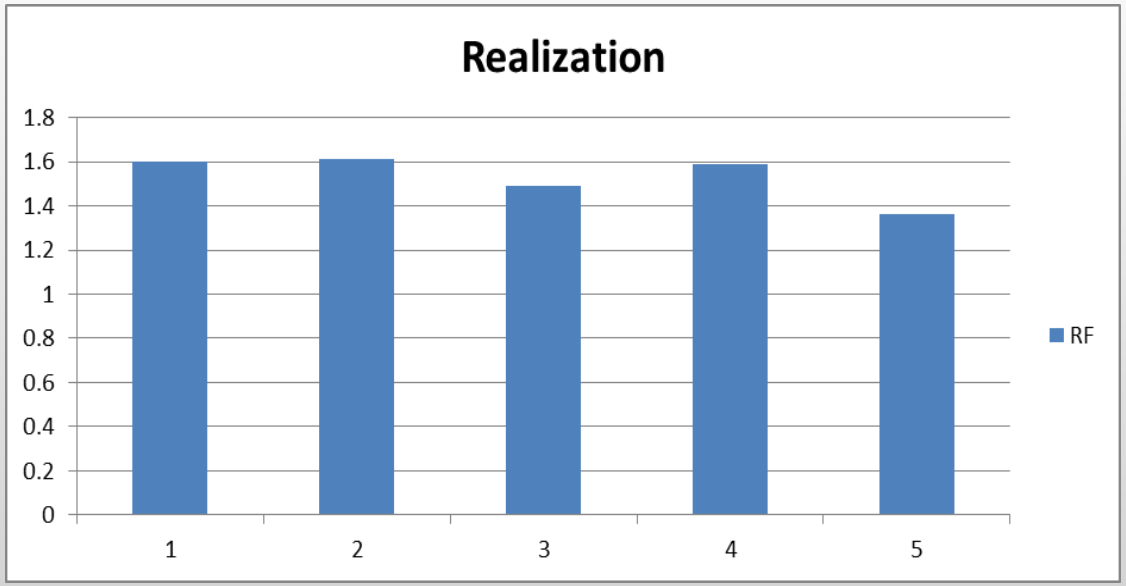
Improvement of "People"

- Reminder: Realization Factor computation

$$\frac{\text{Actuals}}{\text{Labor Standards}} = \text{Realization Factor}$$

- Realization Factor trends can be tracked, and learning theory can be used to model the trend
  - Theoretically, realization factors are tied to the workforce's ability to execute to the standards
  - Over time, a stable workforce with a stable manufacturing process and environment should improve in it's execution towards the standards
  - Opportunities for labor improvement within the confines of a given process diminish over time (improvement at decreasing rate)



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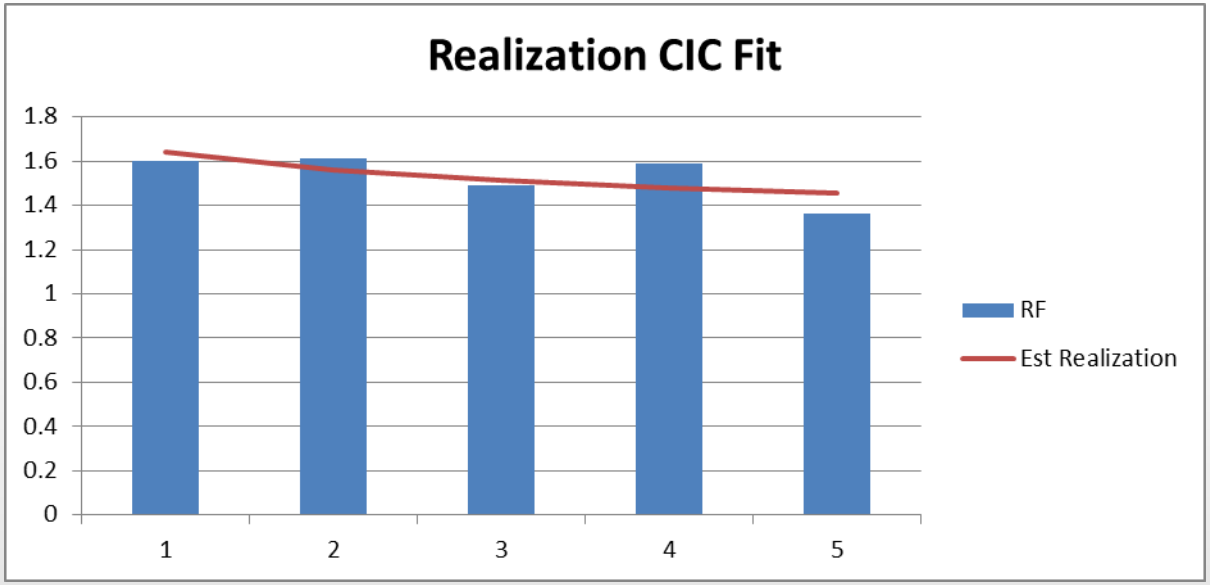
Realization Factor Cost Improvement



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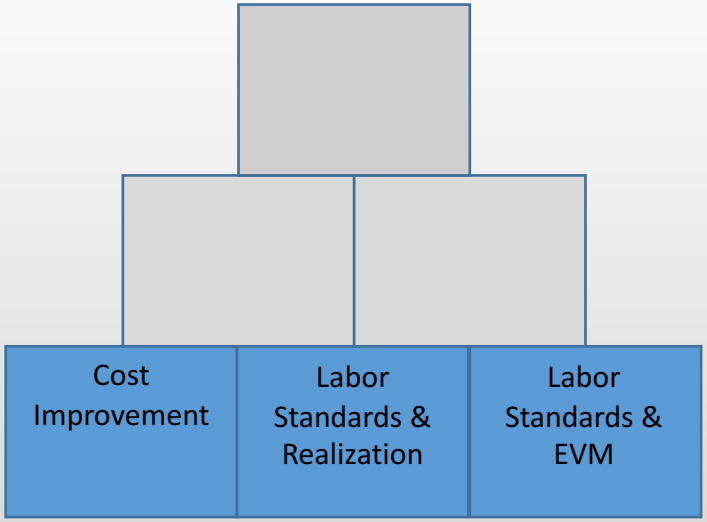
Labor Standards and EVM



Labor Standards' relation to BCWS & BCWP

- OSD's Contract Pricing Finance Guide relates labor standards to EVM
- "Work Measurement System Plan. A Work Measurement System Plan is the firm's program for implementing, operating, and maintaining work measurement in its operations. It is the key to an effective Work Measurement System with a defined system clear responsibility assignments. As a minimum, the Plan should provide guidance on:
  - Establishing and maintaining standard accuracy;
  - Conducting engineering analyses to improve operations;
  - Revising standards and related system data; and
  - **Using labor standards as an input to budgeting, estimating, production planning, and performance evaluation."**

Text above is from Contract Pricing Finance Guide http://www.acq.osd.mil/dpap/cpf/docs/contract_pricing_finance_guide/vol2_ch8.pdf

Remember, in EVM…

- Budgeted Cost of Work Scheduled (BCWS) is the sum of the budgets for all work scheduled to be accomplished within a given time period
- Budgeted Cost of Work Performed (BCWP) is the budgeted cost of work that has actually been performed in carrying out a scheduled task during a specific time period

EVM as a Proxy for Standards

- Based on the guidance for work measurement plans directing the use of labor standards
  - By design, BCWP and BCWS ***should*** have a direct relationship to labor standards

…thus

  - The improvement of BCWS/P over time ***should*** mirror that of the labor standards (with some amount of error)

…and

  - We can calculate and analyze a budget realization factor as a proxy to analyzing the underlying labor standards realization

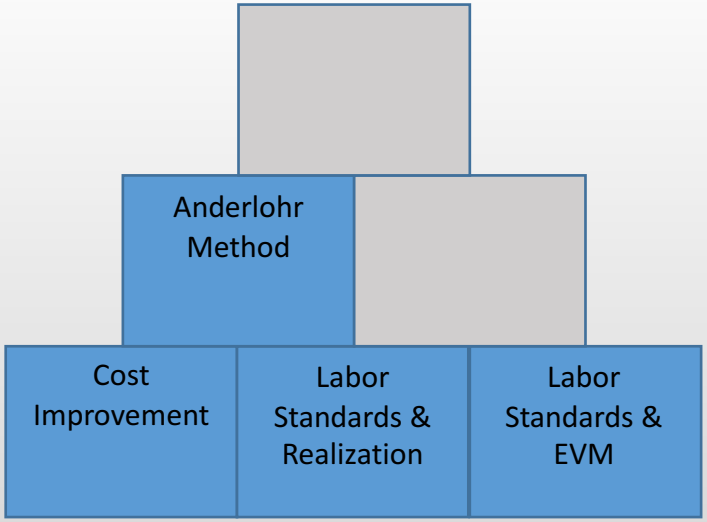
$$\frac{\text{Actuals}}{\text{BCWP}} = \text{Budget Realization Factor}$$

…but

  - Error exists to the extent BCWP/S and standards are uncorrelated

In the absence of labor standards, EVM metrics can potentially be used as a proxy

Anderlohr Method



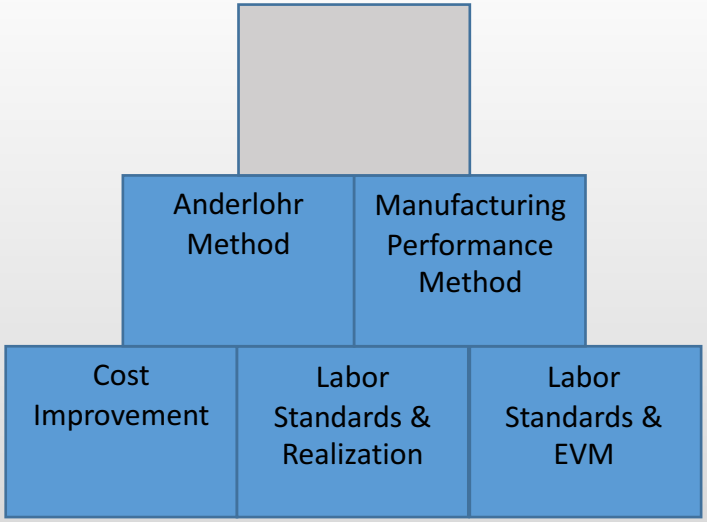
Production Break

- A break in production occurs when production is disrupted for any number of reasons
  - Possible reasons include: labor strike, contract protest, natural disaster, relocation of plant, halt of production by government
  - Gaps in production can last for months or years
- Anderlohr developed a method for assessing the costs associated with a production break

Anderlohr Theory

- Anderlohr categorized cost improvement in a recurring manufacturing environment into 5 categories
  - Personnel Learning
  - Supervisory Learning
  - Continuity of Productivity
  - Methods
  - Special Tooling
- When a production break occurs, analyst assesses manufacturing process
  - Analyst subjectively assesses loss of learning to each of the 5 categories
  - Analyst assigns weights to each category according to its relative impact on Cost Improvement
  - Calculates an overall decrement to cost improvement
- Biggest criticism of Anderlohr is the error associated with using subjective analysis to estimate

Manufacturing Performance Method



Proposition: Manufacturing Performance Method

- Map Anderlohr into “People” and “Process”
  - Allows splitting loss of learning analysis into two parts: Labor Standards and Realization Factors
  - Learning can be assessed on both parts, then loss of learning analysis performed
- Benefits:
  - Can help reduce some subjectivity
  - Arguably easier to work with for estimators
- Difficulties:
  - Government estimators often don’t have access to labor standards

If labor standards are not available, consider EVM as proxy

Mapping the Anderlohr Categories of Lost Learning

1. Personnel Learning
2. Supervisory Learning
3. Continuity of Productivity
4. Methods
5. Special Tooling

People Related

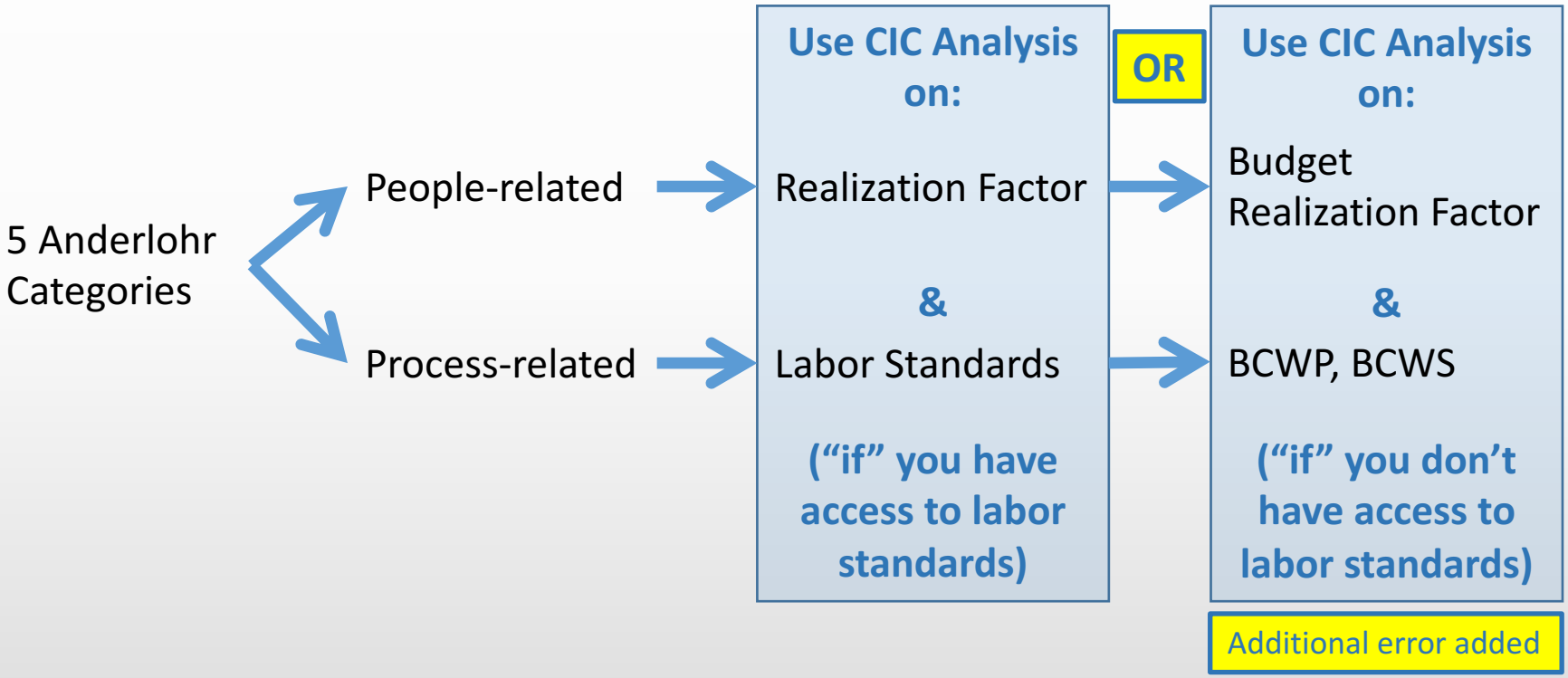
Process Related

Postulation

1. Anderlohr's process-related categories can be represented by the Labor Standards
2. Anderlohr's people-related categories can be represented by the Realization Factor
3. Given the below are true, analyst can focus efforts on Realization analysis, because process impacts can be assumed away
   a) Relatively short production break
   b) Production is understood to have a high chance of continuing after the gap
   c) Manufacturing floor space is dedicated where tooling will remain in place and configured or any reconfiguring needed is minimal
   d) No changes to the production process are expected
4. An acceptable level of error is associated with these assumptions

If labor standards are not available, consider EVM as proxy

Summary of Logic Flow



Mapping Loss to Standards and Realization Factors

- The learning recorded in the labor standards is the “Process” related learning
  - This learning is documented in the production plan and work instructions and is protected from loss of learning even through relatively long production breaks
  - Special tooling will be retained through gaps where production is expected to resume after the gap
  - **Thus, we assume (with some error) no loss, or minimal loss of learning pertaining to our projections of labor standards (or BCWS) for short gaps where production is expected to continue after the gap**

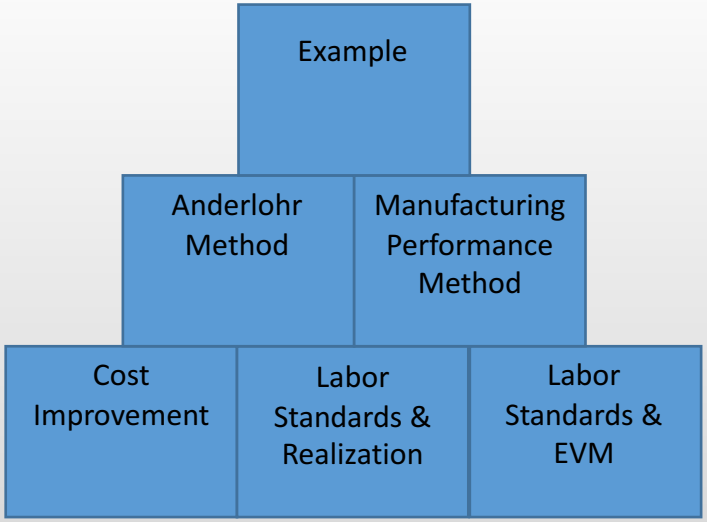
Mapping Loss to Standards and Realization Factors (Cont)

- The learning recorded in the realization factor is the “People” related learning
  - Realization factor is a function of violations in underlying assumptions related to labor standards
    - Qualified worker
    - Pace ordinarily used
    - Under capable supervision
    - Experiencing normal fatigue and delays
    - Defined amount of work
    - Of a specified quality
    - Following the prescribed method
  - As such, improvements to realization are much more perishable than improvements to standards
  - **Thus, we expect a loss of learning pertaining to our projections of realization after the gap**

Important question to ask: What percent of the workforce is expected to return after the production break?

Note: Other complications can arise that might need to be considered, such as supplier base issues

Example


Example
Anderlohr Method
Manufacturing Performance Method
Cost Improvement
Labor Standards & Realization
Labor Standards & EVM

Scenario

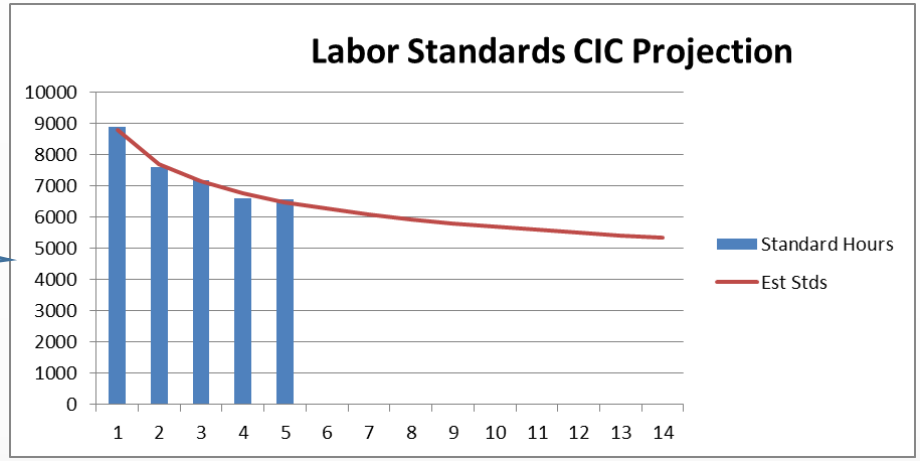
- Using our made up data, we estimate the impacts of a production break of 4 months, occurring after unit 5.

Procedure: Step 1

- Project future Standard Hours with no adjustment

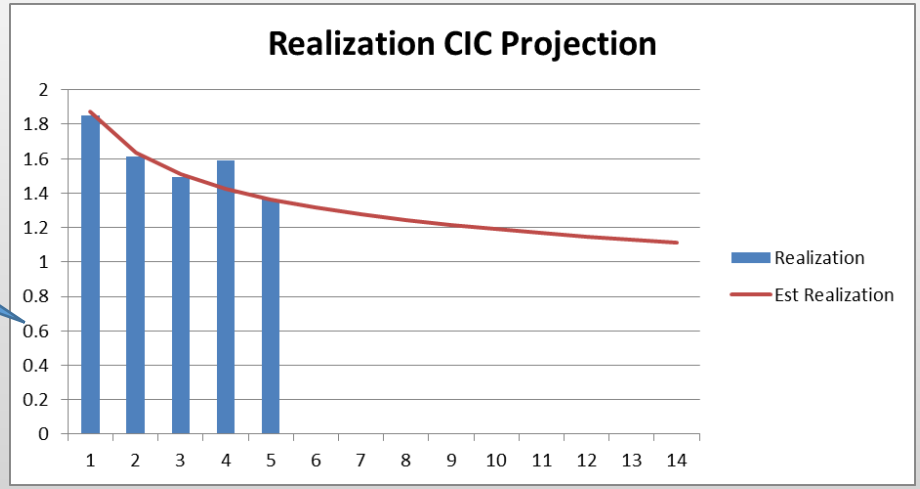
	Stds	Realiz
T1	8,786	1.87
Slope	87.76%	87.22%
b	-0.19	-0.20

Use BCWP data



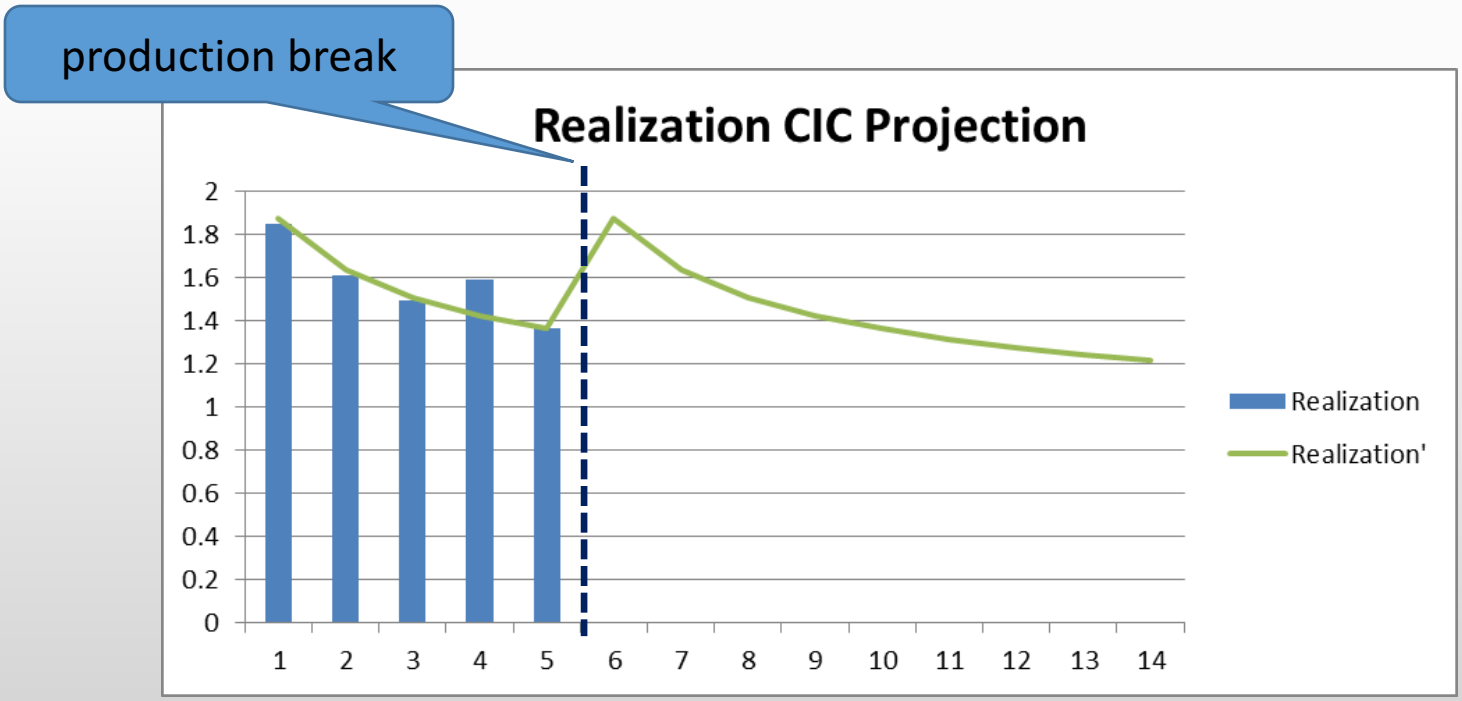
- Project future Realization Factors (unadjusted baseline case)

Actuals/BCWP



Procedure: Step 2

- Based on our assumptions, the Standard Hours projection does not change (unless you have specific reasons to do so based on knowledge of the program)
- For a worst case scenario, we assume all the “People” related learning is lost, going back to T1.



Procedure: Step 3

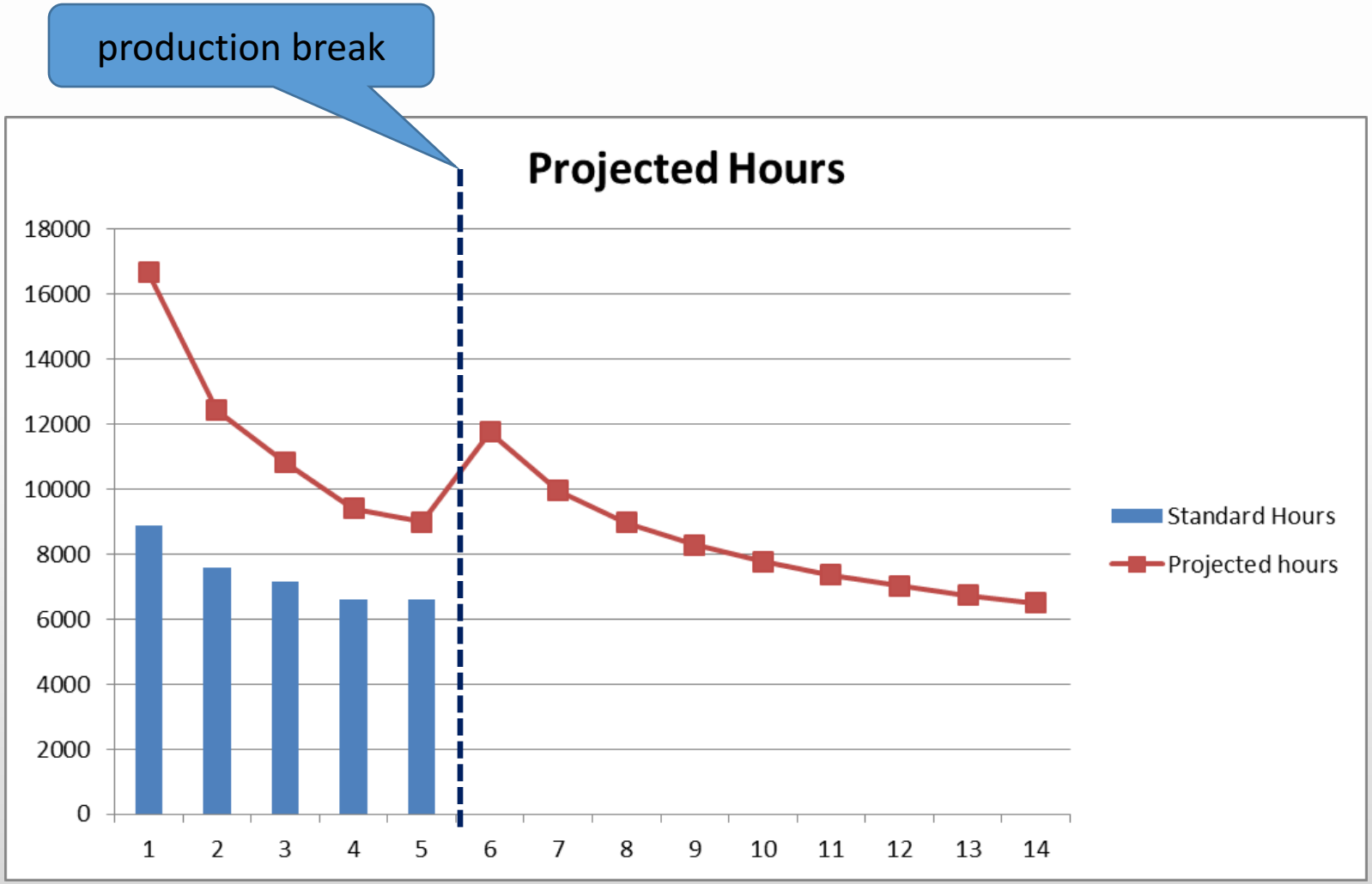
- Multiply projected realization factors by projected standards

	Stds	Realiz
T1	8,786	1.87
Slope	87.76%	87.22%
b	-0.19	-0.20

Prod unit	Standard Hours	Act	Realizatio n	Est Stds	Est Realization (baseline)	Realization' (adjusted for gap)	Projected hours
1	8,894	16,460	1.85	8,786.5	1.87	1.87	16,667
2	7,596	12,259	1.61	7,711.0	1.63	1.63	12,416
3	7,171	10,698	1.49	7,144.0	1.51	1.51	10,820
4	6,595	10,480	1.59	6,767.2	1.43	1.43	9,401
5	6,587	8,991	1.36	6,488.6	1.36	1.36	8,986
6				6,269.6	1.32	1.87	11,749
7				6,090.1	1.28	1.63	9,954
8				5,938.9	1.24	1.51	8,961
9				5,808.6	1.21	1.43	8,281
10				5,694.4	1.19	1.36	7,768
11				5,593.1	1.17	1.32	7,361
12				5,502.2	1.15	1.28	7,024
13				5,419.8	1.13	1.24	6,739
14				5,344.7	1.11	1.21	6,493

Note: Realization' takes into account the impact of the production break

Projected Hours after Gap



Cautions

- Potential sources of error exist with these methods
  - Verify plausibility of assumptions with production SMEs
  - Using EVM as proxy for labor standards adds potential error to the extent BCWP/S and labor standards are uncorrelated
- EVM data will generally not be available for mature production programs
- Sometimes contractors will take advantage of the production break to improve the production line
  - Impact to labor standards CIC would be positive
  - Will likely worsen realization factor upon restart
- This presentation only pertains to recurring manufacturing
- Research needed on the difference between labor standards and BCWP/BCWS

Key Take-Aways

- Cost Improvement Curve (CIC) analysis is a primary tool for estimating recurring manufacturing
- Labor standards and realization factors can be analyzed using CIC methodology to estimate production costs
- Anderlohr Methodology provides a framework to estimate the cost of production breaks
- Labor standards and realization factors can be used within Anderlohr's framework to estimate production breaks
- Recurring manufacturing EVM data can potentially be used as a proxy for labor standards, with some error
- A good understanding of the manufacturing process is necessary to tailor analysis

Feel free to email me questions or comments at:

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