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Cost Estimating Techniques

The basic types of cost estimates

"Prediction is very difficult, especially if it's about the future." [disputed]
-Niels Henrik David Bohr (1885-1962), Danish physicist and Nobel laureate

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Acknowledgments

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Unit Index

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Cost Estimating Techniques Overview

- Key Ideas
  - Cost Estimating Techniques
    - Analogy
    - Parametric
    - Build-up
    - Extrapolation from Actuals
  - Cost Element Structure (CES)
- Practical Applications
  - Estimate Development
  - Cross-checks
- Analytical Constructs
  - Basic Mathematical Operations
    - Addition, Multiplication, Powers
  - Ratios and Linear Relationships
  - Curve Fitting
  - Hierarchical Tree Structure
- Related Topics 2
  - Below-The-Line (BTL) Factors
  - 2 Schedule Estimating
  - Operations and Support (O&S) Estimating 2

A Bridge to the Future

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http://commons.wikimedia.org/wiki/Image:Pierre_Pflimlin_UC_AdjAndCrop.jpg

The Cost Estimating Framework

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Past — *Understanding your historical data*

Present — *Developing estimating tools*

Future — *Estimating the new system*

- Identical, off-the-shelf item
  Catalog price
- Identical items / capabilities
  Predicted inflation - recent historical trends (5)
- Manufactured items
  Learning curve - complete production run (7)
- Similar new development items
  CERs - historical costs from several programs (3)
- Dissimilar new development items
  Adjusted CERs - historical costs from several programs + paradigm shift

The further in the future you want to estimate, the further back you need to go into the past!

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Cost Estimating Techniques Outline

- Core Knowledge
  - Introduction
  - Uncertainty and Risk
  - Cost Estimating Techniques
  - Using Cost Estimating Techniques
  - Comparison of Techniques
- Summary
- Resources
- Related and Advanced Topics

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Introduction

- The four essential cost estimating techniques (or methodologies) are:

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  - Analogy
  - Parametric
  - Build-Up
  - Extrapolation from Actuals
- Other topics will be discussed in relation to the four essential techniques
  - Expert Opinion

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Risk Terminology

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- Precision vs. accuracy
  - Precision = narrow range
  - Accuracy = range centered on “right” answer

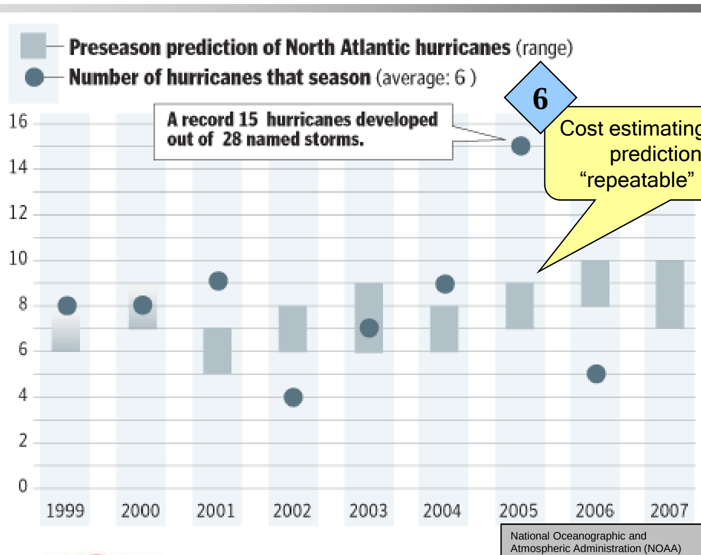
Tip: We want estimates to be both precise and accurate, but imprecisely accurate is better than precisely inaccurate!

- Uncertainty vs. risk
  - Uncertainty = range of possible outcomes
    - Characterization of precision
  - Risk = shift of range to account for lack of accuracy of unadjusted estimates

Correction of bias

Warning: Uncertainty and risk are difficult but essential.

Uncertainty and Risk Example



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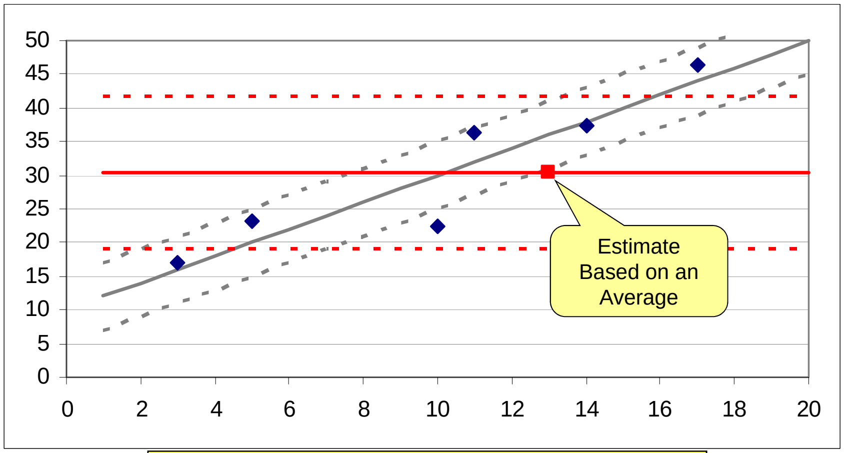
Cost estimating, like weather prediction, is not a “repeatable” experiment!

7

Uncertainty and Risk Illustration



Tip: Estimating cost as an average of historical data is generally a good starting point

Cost Estimating Techniques

- Analogy
- Parametric
- Build-Up
- Extrapolation from Actuals

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Cost Estimating Techniques Basics

- Cost Estimating Techniques provide the structure of your cost estimate
  - They're what enable you to predict future costs based on historical data
  - Techniques rely on statistical properties, logical relationships, and emotional appeal
- Four essential types
  - Analogy: "It's like one of these"
  - Parametric: "This pattern holds"
  - Build-Up: "It's made up of these"
  - Extrapolation from Actuals: "Stay the course"

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Analogy - Method

- Comparative analysis of similar systems
- Adjust costs of an analogous system to estimate the new system, using a numeric ratio based on an intuitive physical or countable metric
  - e.g., weight, SLOC, number of users
- Other adjustments may need to be made for *any* estimating methodology
  - Programmatic information (quantity/schedule)
  - Government vs. Commercial practices
  - Contract specifics
  - Economic trends

3

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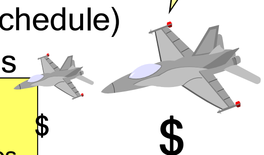
"It's like one of these"



AKA Comparison Technique, Ratio, Analysis of Analogues

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Analogy - Application

- Used early in the program life cycle
  - Data are not available to support using more detailed methods
  - Not enough data exist for a number of similar systems, but can find cost data from a single similar system
- The best results are achieved when
  - Adjustments can be quantified
  - Subjective adjustments are minimized
  - Similarities between old and new systems are high
    1. Minimize differences to one or more that can be scaled, *then*
    2. Minimize the amount of scaling (size of adjustment factor)
- Can be used as a cross check for other methods

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Analogy - Considerations

- Strengths
  - Can be used early in programs before detailed requirements are known
  - Difficult to refute if there is strong resemblance
- Weaknesses
  - No objective test of validity
  - Danger in choice of scaling factor
    - Which variable
    - Functional form (linear vs. non-linear scaling)
    - What slope (through origin or borrowed slope)
- Challenges
  - Difficult to obtain cost/technical data on old/new systems for comparison

Warning 1: An adjusted analogy is like a regression, but the slope is just a guess.

Warning 2: An adjusted analogy is, by definition, estimating outside the range of the data.

Analogy - Example

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Attribute	Old System	New System
Engine:	F-100	F-200
Thrust:	12,000 lbs	16,000 lbs
Cost:	$5.2M	?

Tip: The mischief in analogy most often arises in the adjustment. Why do we so readily believe a linear relationship which passes through the origin?

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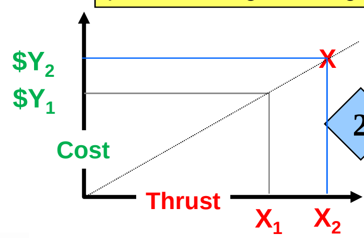
Q: What is the unit cost of the F-200?

A: $5.2M * (16,000/12,000) = $6.9M

or

($5.2M/12,000) * 16,000 = $6.9M



Warning 1: An adjusted analogy is like a regression, but the slope is just a guess.

Warning 2: An adjusted analogy is, by definition, estimating outside the range of the data.

Analogy - Uncertainty and Risk

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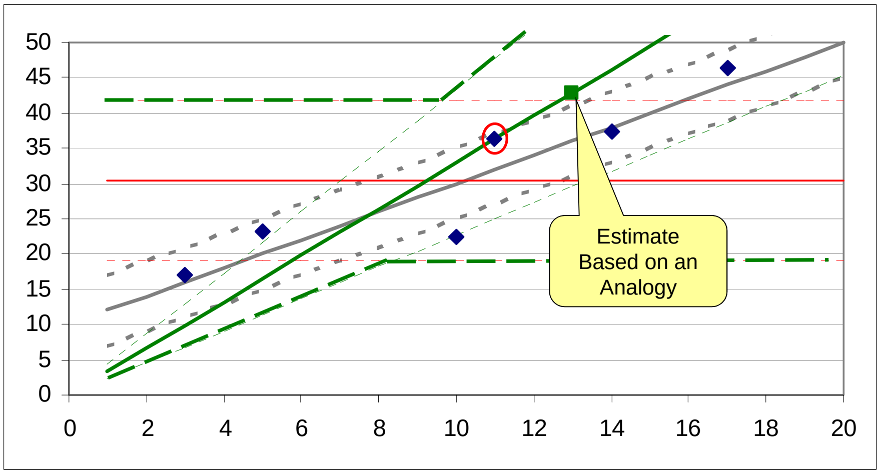
- Uncertainty
  - Uncertainty in point of departure
  - Uncertainty in slope of adjustment
- Risk
  - Risks not "included" in analogy system
  - Historical growth of scaling quantity

"Analogies: Techniques for Adjusting Them," R. L. Coleman, J. R. Summerville, S. S. Gupta, SCEA 2004.

Analogy – Uncertainty/Risk Illustration

v1.2



Parametric Estimating - Method

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3 • A mathematical relationship between a parameter and cost

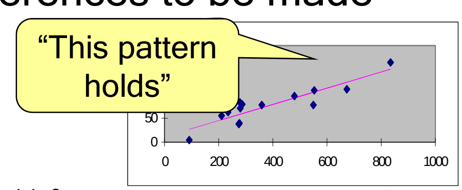
4 – Parameter may be physical, performance, operational, programmatic, or cost

9 • Uses multiple systems to develop relationship

Warning: Rates, factors, and ratios in use may not be statistically based.

8 • Allows statistical inferences to be made

AKA Cost Estimating Relationships (CERs), Rates, Factors, Ratios 3



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Parametric Estimating - Application

- Use of Parametrics
  - 4 Requires a good database which is relevant to the the system being estimated
  - Excellent for use early in program life cycle before a detailed design exists
  - Used as the design progresses to capture changes
    - 16 CAIV trades
- Good as a cross-check for other methods

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Parametric Estimating – Considerations

- Strengths
  - Can be easily adjusted for changes by modifying input parameters
  - Sensitivity Analysis - Can show how changes to certain parameters impact the cost
  - 8 Objective measures of validity
  - 9 Statistical measures for uncertainty
- Weaknesses
  - "Black box syndrome" with pre-existing CERs, commercial models
- Challenges
  - 4 Difficult to ensure consistency and validity of data
    - Goal is to establish and maintain homogeneous data set
  - 7 Must constantly review relationships to ensure that relationships reflect current status of relevant programs, technology, and other factors

v1.2

Parametric Estimating - Example

- CER for Site Activation as a function of Number of Workstations:
  - Site Act ($K) = 82.8 + 26.5 * Num Wkstn
  - Site Activation includes site survey and site installation costs for an Automated Information System (AIS)
- Estimated based on 11 data points for installations ranging from 7 to 47 workstations
- Example expanded in Module 3

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3

v1.2

Parametric Estimating - ERP Example

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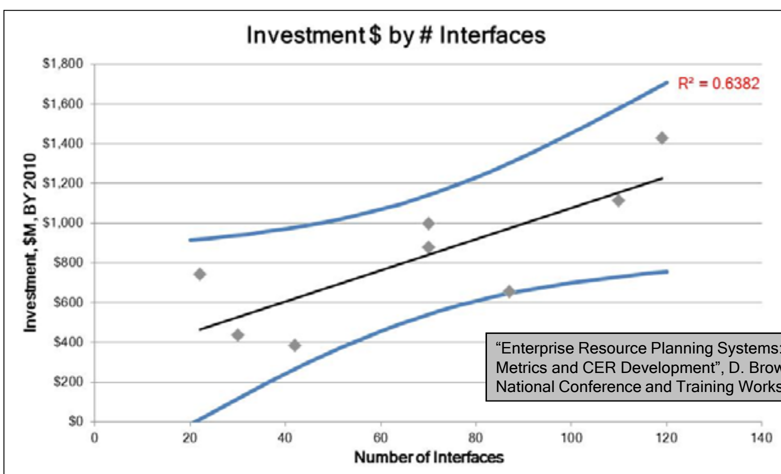
- The graph below shows an example CER for ERP investment as a function of the Number of Interfaces:



"Enterprise Resource Planning Systems: Sizing Metrics and CER Development", D. Brown, SCEA National Conference and Training Workshop, 2011

NEW!

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Parametric - Uncertainty and Risk

"bounce" and "wiggle"

- Uncertainty
  - 8 9 Uncertainty in intercept and slope of regression line
    - Standard error → Confidence Interval (CI)
  - 18 Uncertainty in distribution around regression line
    - SEE → Prediction Interval (PI)

"fuzz" or "noise"

- Risk
  - Risks not "included" in historical data set
  - Historical growth of cost driver(s)

Tip: Parametric has the strength of using statistical results to capture the uncertainty in estimating beyond the range of the data

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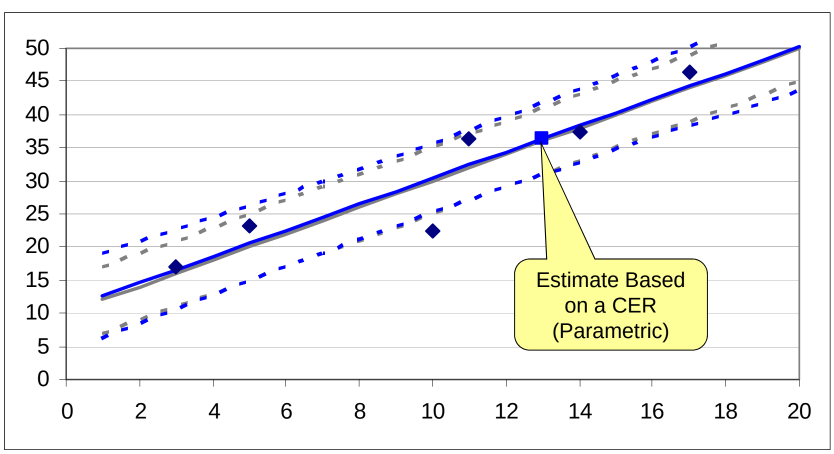
Parametric - Uncertainty/Risk Illustration



Parametric - Uncertainty/Risk Illustration

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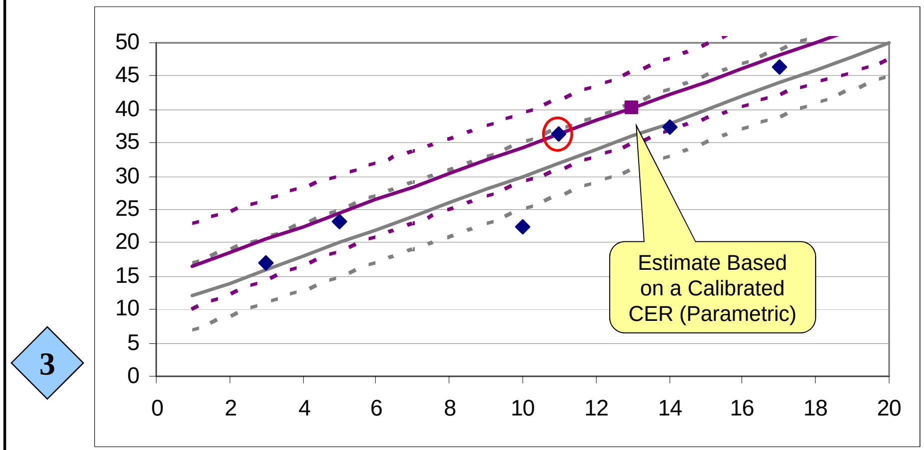
Calibrated CER



Uncertainty and Risk Illustration

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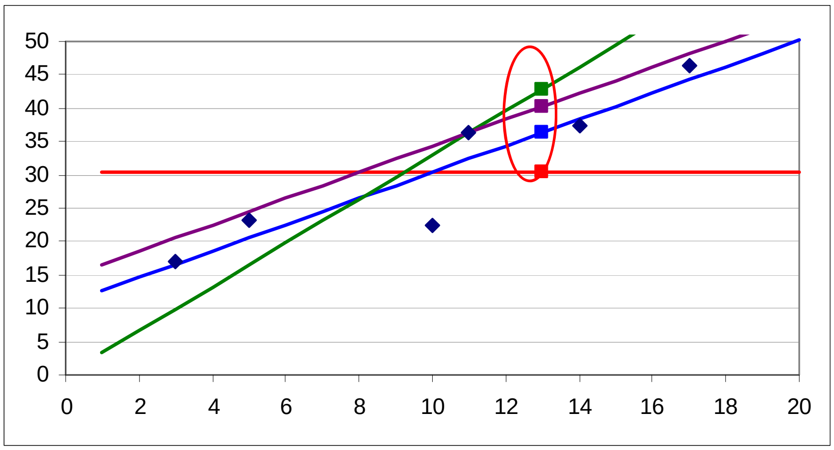

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Build-Up - Method

- Estimating is done at lower levels and results rolled up to produce higher-level estimates
  - Often the lowest definable level at which data exist
- Elements of this method could include
  - Standards
  - Time and Motion Studies
  - Well defined work flow
  - Variance Factors
  - Parts List
  - Lot Size and Program Schedule Considerations
  - Program Stage
  - Support Labor

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"It's made up of these"

AKA Engineering Build-Up, Industrial Engineering (IE), Time Standards, Standard Labor Hours, Catalog/Handbook, Detailed Cost Estimating

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Build-Up - Application

- Used when you know detailed product information at the lowest level (i.e., hours, material, etc.)
- Used in a manufacturing environment where Touch Labor can be accurately estimated
  - Touch Labor = direct work on product
    - As opposed to support or management functions

Tip: Engineering drawings (e.g., CAD/CAM) or site surveys are almost always required to do a build-up

Warning: In application, "engineering judgment" often masquerades as engineering build-up, because they are both bottom-up

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Build-Up – Considerations

- Strengths
  - Easy to see exactly what the estimate includes
  - Can include Time and Motion Study of actual process
  - Variance Factors based on historical data for a given program or a specific manufacturer
- Weaknesses
  - Omissions are likely
  - Small errors can be magnified
- Challenges
  - Expensive and requires detailed data to be collected, maintained, and analyzed
  - Detailed specifications required and changes must be reflected

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Build-Up - Example

- Problem: Estimate hours for the sheet metal element of the inlet nacelle for a new aircraft
  - Similar to F/A -18 E/F nacelle which has a 20% variance factor (actuals to standards) and a support labor factor of 48% of the touch labor hours
  - The standard to produce the sheet metal element of the new inlet nacelle is 2000 touch labor hours
- Solution: Apply F/A-18 E/F factors to the standard touch labor hours
  - 2000 hrs x 1.2 = 2400 touch labor hours
  - Add the support factor of 48% to get the total hours estimate of 2,400 x 1.48 = 3,552 hours

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Build-Up - Uncertainty and Risk

- Uncertainty
  - Uncertainty in Design Specs
  - Uncertainty in performance to standards (labor)
  - Uncertainty in unit costs, scrap rates (material)
- Risk
  - Omissions
  - Historical growth of design specs
  - Difficulty of integration

Extrapolation from Actuals

- Extrapolation from actuals is a subset of some methods
  - Using actual costs to predict the cost of future items of the *same* system
- Extrapolation is used in several areas, which include:
  - Averages
  - Learning Curves
  - Estimate at Completion

7

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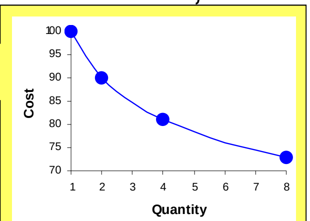

"Stay the course"

2

AKA Averages; Learning Curves, Cost Improvement Curves, Cost/Quantity Curve; Estimate at Completion (EAC), or Earned Value (EV)

Extrapolation from Actuals - Application

v1.2

- Best application is for follow-on production units/lots
- Requires accurate cost database
  - At an appropriate level of cost detail
  - Validate and normalize data
- Once sufficient actuals are accrued, can be used to determine Estimate At Complete (EAC) throughout remainder of current phase

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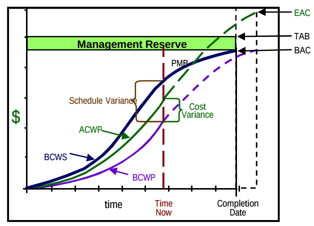
Earned Value Management
'Gold Card'



Tip: Improved integration between the cost estimating and earned value functions has lead to increased prevalence of this estimating method

Extrapolation from Actuals - Considerations

v1.2

- Strengths
  - Utilizes actual costs to predict future costs
  - Can be applied to hours, materials, total costs
  - Highest credibility and greatest accuracy when properly applied
  - Many government bodies require or encourage the use of this technique
- Weaknesses:
  - Work to date may not be representative of work to go
  - Extrapolating beyond a reasonable range
- Challenges:
  - Unknown events affecting bookkeeping of actuals
  - Changes in cost accounting methods
  - Contract changes affecting actuals
  - Configuration changes, process changes all have impacts

Extrapolation from Actuals – Uncertainty and Risk

v1.2

- Uncertainty
  - Uncertainty in Learning Curve 7
  - Uncertainty in EAC 15
- Risk
  - Insufficient cost history
  - Cost history not representative of future work
  - Unrealistic baselines, excessive optimism, and the EAC "tail chase"

"Do Not Sum Earned-Value-Based WBS-Element Estimates-at-Completion", S.A. Book, SCEA National Conference and Training Workshop, 2000

v1.2

Expert Opinion

Expert Opinion - Method

v1.2

- Uses an expert or a group of experts to estimate the cost of a system
  - One-on-one interviews
  - Round-table discussions
  - Delphi Technique

1

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AKA Engineering Judgment, Round Table, Delphi Technique

Tip: Expert Opinion refers to *direct assessment of costs*. Expert judgment is expected to be applied in any of the previously-described legitimate cost estimating techniques.

Warning: Expert Opinion alone is not widely considered to be a valid technique

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Expert Opinion - Application

v1.2

- Only used when more objective techniques are not applicable
- Used to corroborate or adjust objective data
  - Cross check historical based estimate
- Use for high-level, low-fidelity estimating (e.g., sanity check)
- Last resort

Tip: Expert Opinion is the least regarded and most dangerous method, but it is seductively easy. Most lexicons do not even admit it as a technique, but it is included here for completeness.

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Expert Opinion – Considerations

v1.2

- Strengths
  - Good cross check of other estimate from Subject Matter Expert (SME) point of view
  - Provides expert perspective that facilitates understanding
- Weaknesses
  - Completely subjective without use of other techniques
  - Low-to-nil credibility
  - Difficult to run risk around an expert opinion

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Tip: It is preferable to find data to support a credible basis, which may jibe with the expert-based estimate if it is implicitly founded on the same data

Expert Opinion – Uncertainty and Risk

v1.2

- Uncertainty
  - Human tendency to (significantly) understate error bands
- Risk
  - Faulty recollection of "anecdotal actuals"
  - Gaming
  - Excessive optimism (or conservatism)

v1.2

Using Cost Estimating Techniques

- Estimate Requirements
- Top Down vs. Bottom Up
- Cost Element Structure (CES)
- Technique Selection
- Checking Results
- Documentation

v1.2

Estimate Requirements

- Why are we developing this estimate? What will it be used for?
  - Milestone A, B, or C decision
  - Developing a budget
  - Developing a “ballpark” or rough order of magnitude (ROM) estimate
  - Comparing alternatives
  - Developing or evaluating proposals

v1.2

Top Down vs. Bottom Up

- The below definitions are correct, although in practice many terms are used as if they are interchangeable
- Top Down vs. Bottom Up refers to the origin of the estimate
  - Top down (note singular) means either a target or a top-level estimate, which is then allocated to lower levels of the WBS
  - Bottom up (note singular) means estimated at a lower level and then rolled up
- Top-Level vs. Lower-Level (estimate) refers to the level at which an estimate is performed, whether or not it is allocated or rolled up, respectively
- Build-Up is a specific estimating methodology

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- Usual associations:
  - {Top-Level estimate} or {cost target or Price to Win (PTW)} with {Top Down}
  - {Lower-Level} with {Bottom Up}
  - {Bottom Up} with {Build-Up}

v1.2

Cost Element Structure

1

- Determine what needs to be estimated and develop an appropriate Cost Element Structure (CES)
  - CES Dictionary defines what is included in each element
  - Characteristics associated with cost elements that are routinely used to classify costs
    - Program Phase: Development, Production, O&S
    - “Color of Money”: RDT&E, Procurement, O&M
    - Funding Source
    - Non-Recurring or Recurring
    - Direct or Indirect

Tip: Be sure to estimate at a level of the CES that is well supported by defensible data

v1.2

Technique Selection

- Review available techniques
- Compare alternatives
- Select or develop appropriate technique
- Identify primary and secondary techniques

Each cost estimating technique has strengths and weaknesses and can be applied at different times in the life cycle of a cost estimate

v1.2

Checking Results

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- Cross Checking your results greatly increases credibility
  - Example: A parametric-based estimate can also show an analogy as a "reasonableness test"
  - Doesn't necessarily result in the exact same number, but should be a similar number (same order of magnitude)
- An independent* estimate is more detailed than a cross check and attempts to get the same result using a different technique
  - Example: Use the results from one commercial software estimating package to validate the results of another

*Note: "Independent" has many meanings. The most stringent meaning is in Title 10 USC Section 2434 and involves an organization out of the chain of command of the acquiring agency. A looser meaning is an estimate done by an organization unbeholden to the program manager in funding or accountability. The loosest meaning is a separate estimate.

v1.2

Documentation

- Within reason, more information is better than less
- Any information that is used in the analysis must be included in the documentation
- Documentation should be adequate for another cost analyst to replicate your technique
- Like they used to tell you in math class….

If You Don't Show Your Work,
You Don't Get Any Credit!

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Comparison of Techniques

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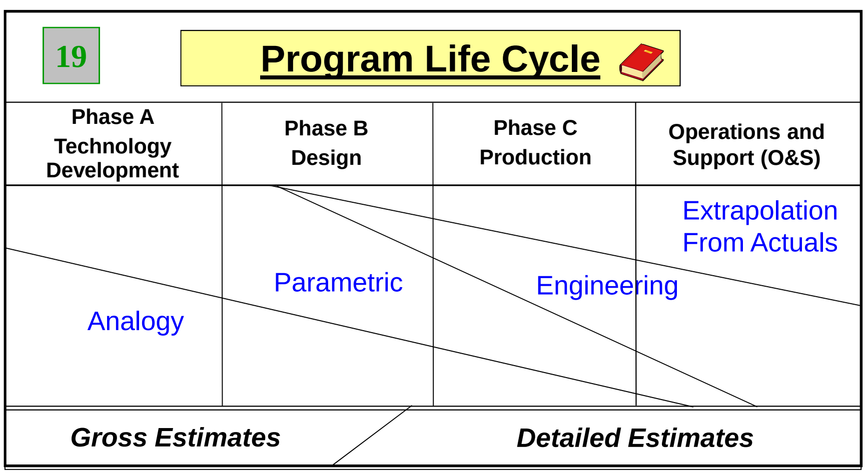
Comparison - Advocacy

- Advocates of Build-Up drink beer and say:
  - More detailed = more accurate
  - Analogy is prey to invalid comparisons
  - Parametric is too "theoretical"
- Advocates of Analogy drink bourbon and say:
  - Like things cost like amounts
  - Build-Up is prey to omission and duplication
  - Parametric is "diluted" by less applicable systems
- Advocates of Parametric drink wine and say:
  - Most thoroughly based on historical data
  - Analogy is just a one-point CER through the origin!
  - Build-Up is prey to omission and duplication

Hey, it's a joke, lighten up!

v1.2

Comparison - Life Cycle Applicability



Integrated Defense Acquisition, Technology and Logistics Life Cycle Management Chart, Defense Acquisition University (DAU), https://ilc.dau.mil/.

Cost Estimating Techniques Summary

v1.2

- You need to have all the cost estimating techniques in your repertoire
- For each, you need to know:
  - What it is
  - When to apply
  - How to execute
  - Strengths and Weaknesses
  - Challenges
  - The supporting data required

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Resources

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- Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management chart, Defense Acquisition University (DAU)
  - https://ilc.dau.mil/
- International Society of Parametric Analysts (ISPA), Parametric Estimating Handbook, 4th Edition, April 2008
  - https://www.iceaaonline.org/documentation/files/ISPA_PEH_4th_ed_Final.pdf

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