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

Acknowledgments

- ICEAA is indebted to TASC, Inc., for the development and maintenance of the Cost Estimating Body of Knowledge (CEBoK®)
  - ICEAA is also indebted to Technomics, Inc., for the independent review and maintenance of CEBoK®
- ICEAA is also indebted to the following individuals who have made significant contributions to the development, review, and maintenance of CostPROF and CEBoK ®
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Cost Estimating Techniques Overview

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- Practical Applications
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  - Cross-checks

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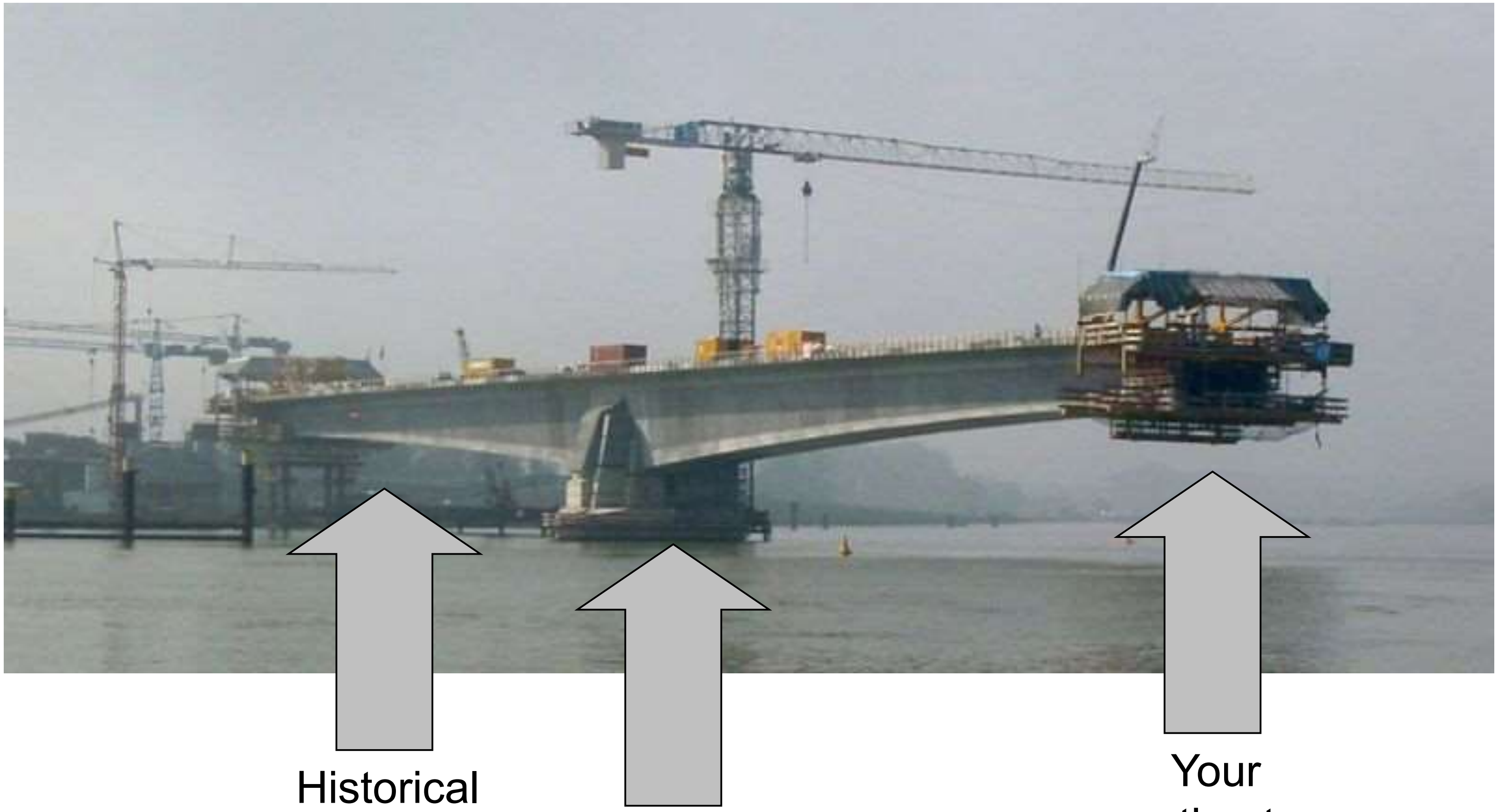
A Bridge to the Future



Historical data

Time now

Your estimate

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

ICEAA CEBoK

The Cost Estimating Framework

Past	**Present**	**Future**
Understanding your historical data	*Developing estimating tools*	*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!

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

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

Risk Terminology

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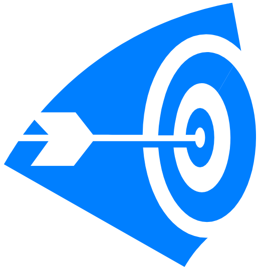


- Precision vs. accuracy
  - Precision = narrow range
  - Accuracy = range centered on "right" answer

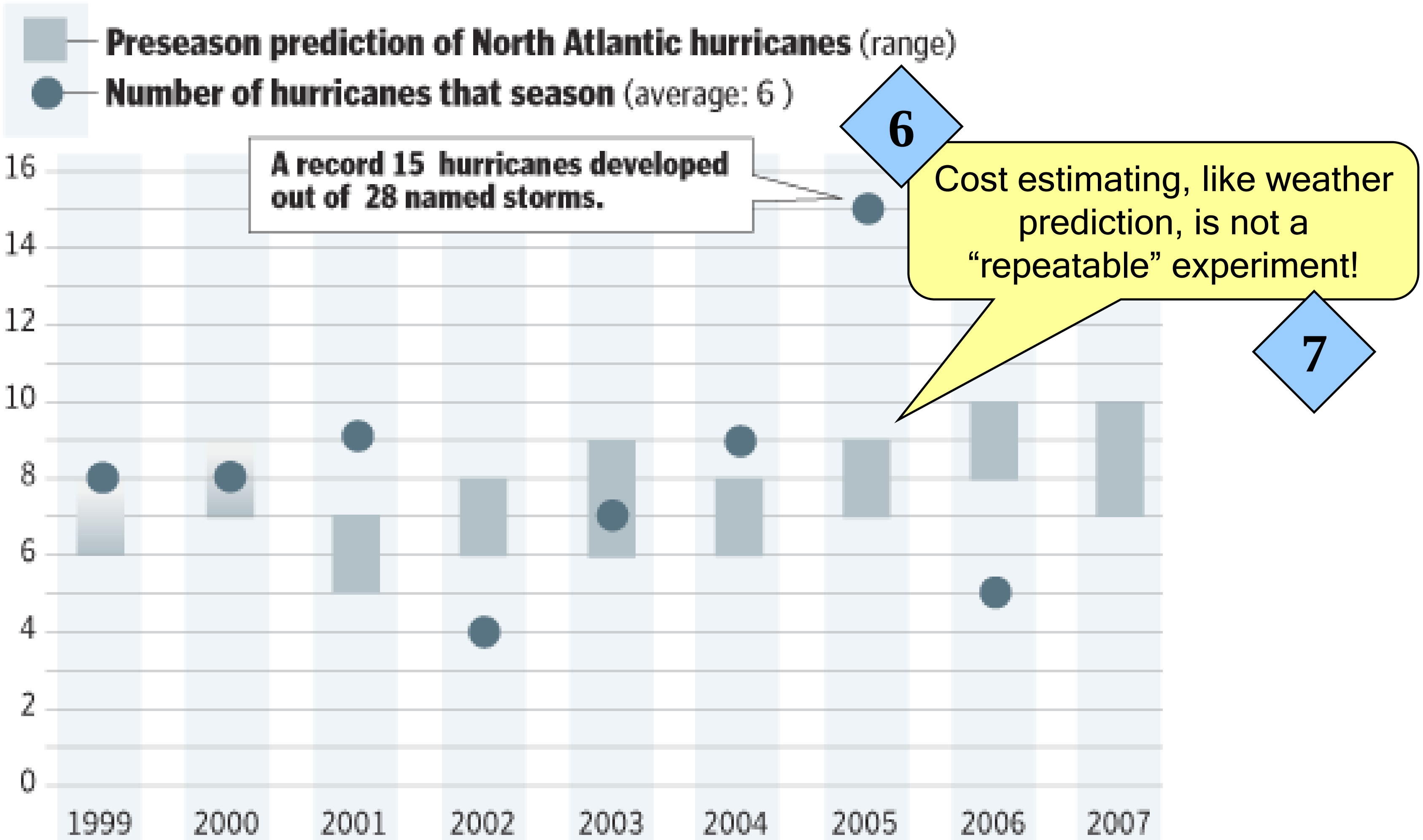
Tip: We want estimates to be both precise and accurate, but imprecisely accurate is better than precisely inaccurate!

- 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

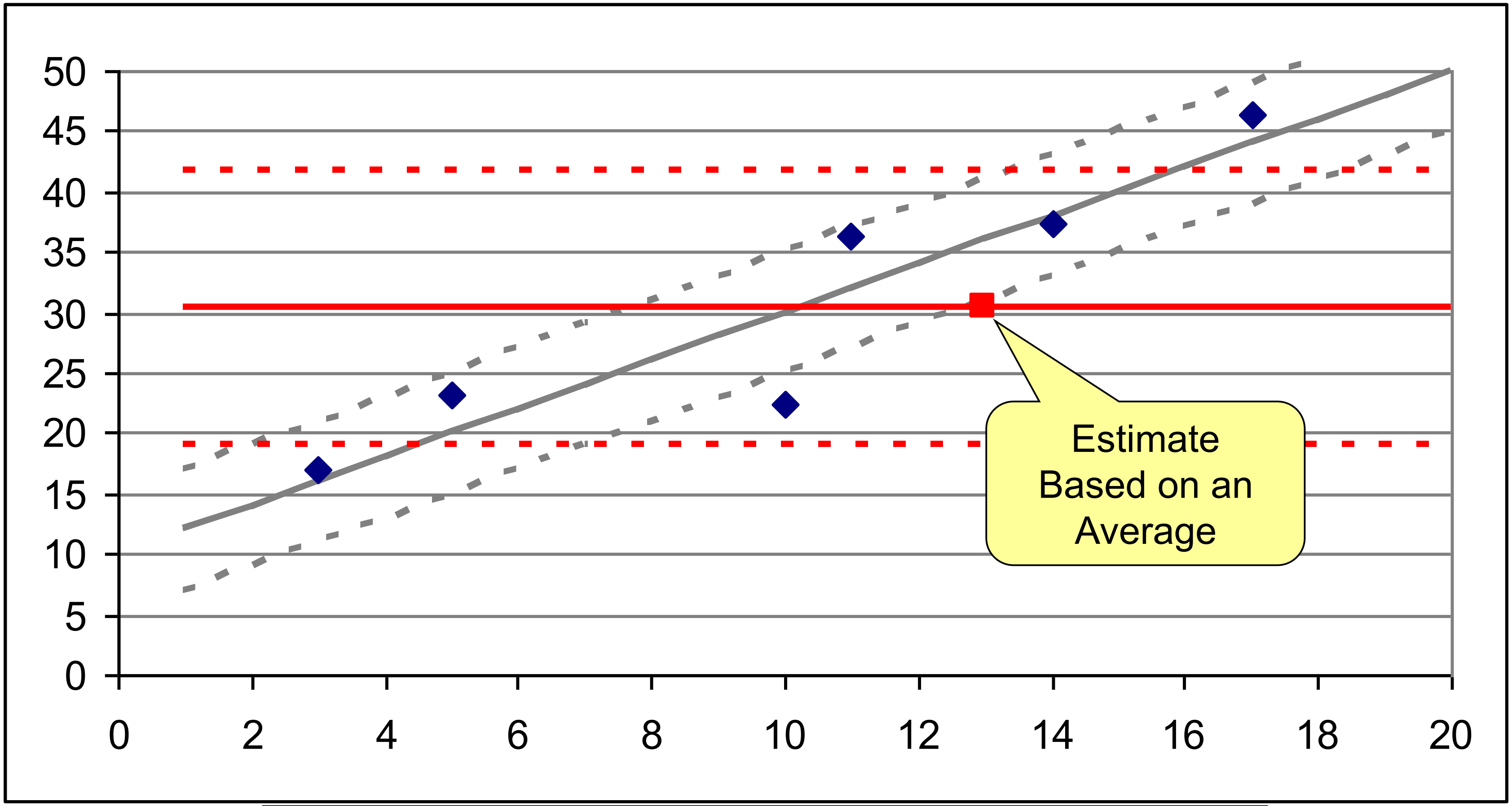
Warning: Uncertainty and risk are difficult but essential.

Uncertainty and Risk Example



National Oceanographic and Atmospheric Administration (NOAA)

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

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"

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

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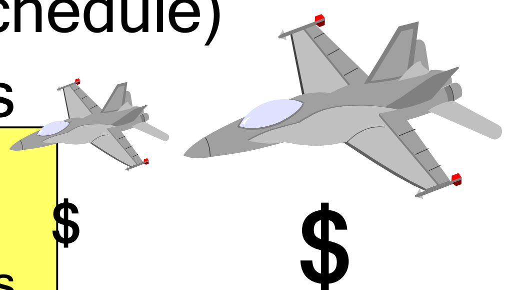
"It's like one of these"

AKA Comparison Technique, Ratio, Analysis of Analogues



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

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

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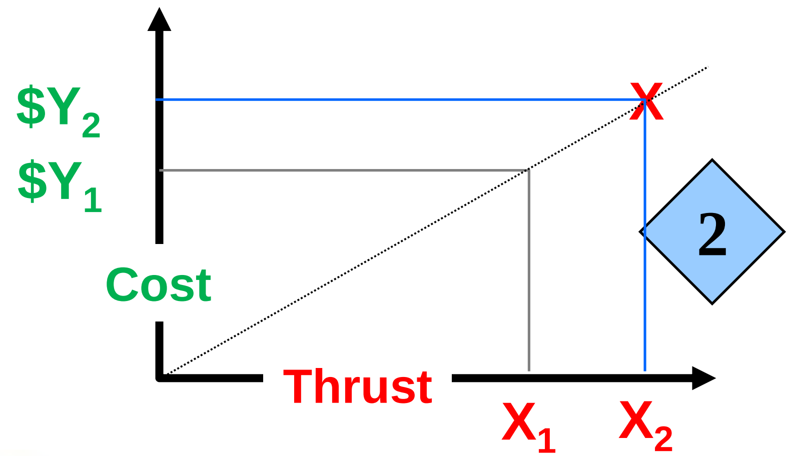
Q: What is the unit cost of the F-200?

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

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

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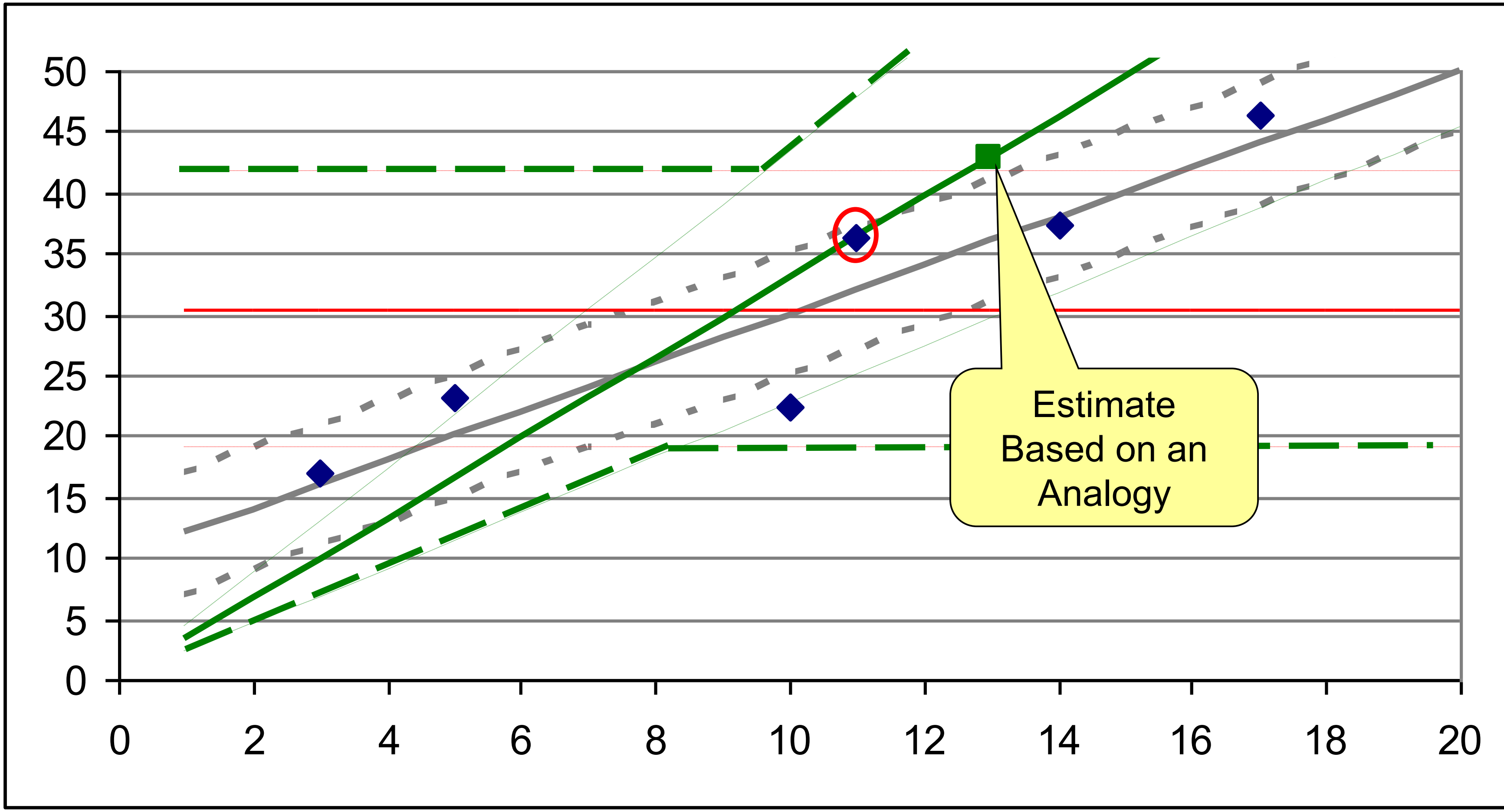
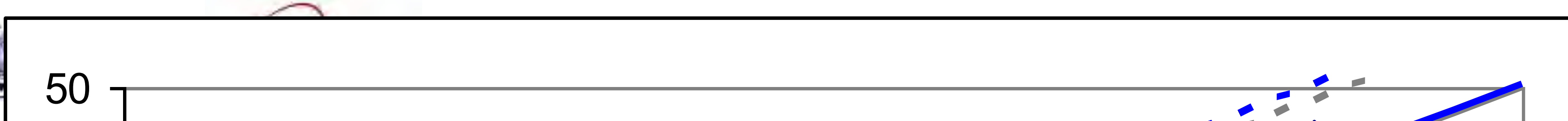
"Analogies: Techniques for Adjusting Them," R. L. Coleman, J. R. Summerville, S. S. Gupta, SCEA 2004.

Analogy - Uncertainty/Risk Illustration





Parametric Estimating - Method

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- A mathematical relationship between a parameter and cost

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  - Parameter may be physical, performance, operational, programmatic, or cost

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- Uses multiple systems to develop relationship

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

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- Allows statistical inferences to be made

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

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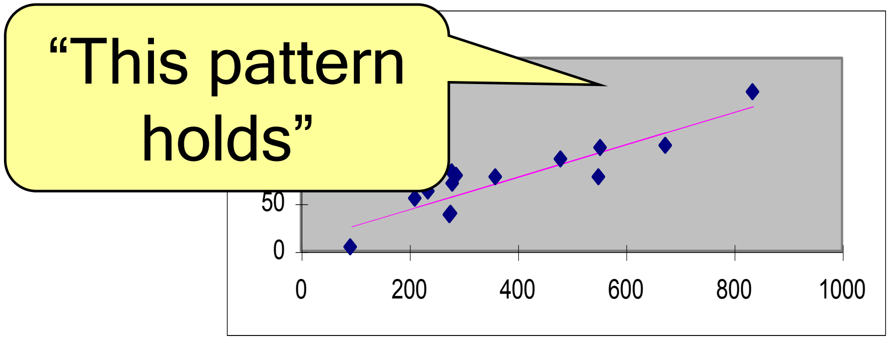

Parametric Estimating - Application

- 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

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
  - Objective measures of validity
  - Statistical measures for uncertainty
- Weaknesses
  - “Black box syndrome” with pre-existing CERs, commercial models
- Challenges
  - Difficult to ensure consistency and validity of data
    - Goal is to establish and maintain homogeneous data set
  - Must constantly review relationships to ensure that relationships reflect current status of relevant programs, technology, and other factors

8 9 4 7

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)

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- Estimated based on 11 data points for installations ranging from 7 to 47 workstations

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- Example expanded in Module 3

Parametric Estimating – ERP Example

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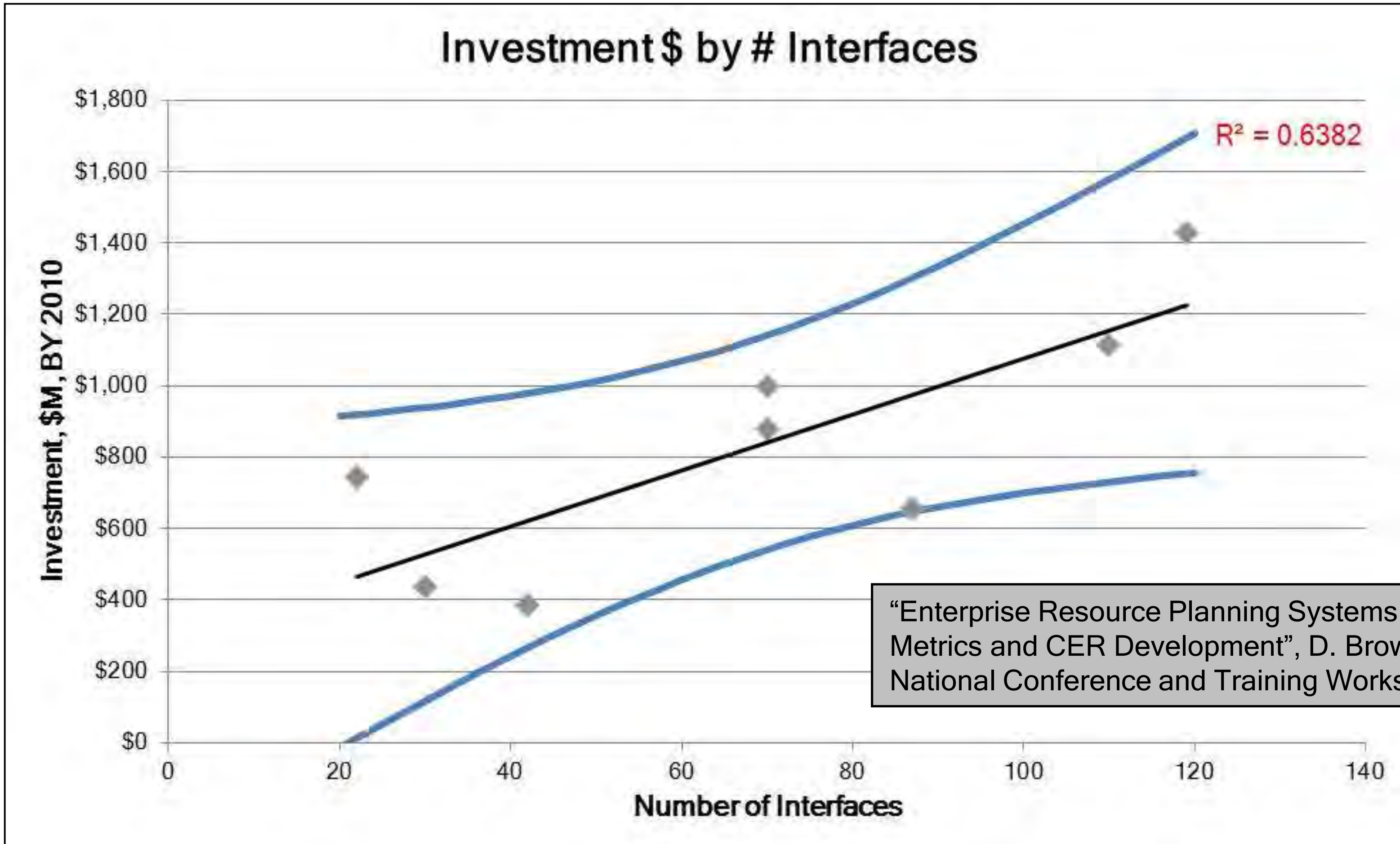
- The graph below shows an example CER for ERP investment as a function of the Number of Interfaces:



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

NEW!

Parametric – Uncertainty and Risk

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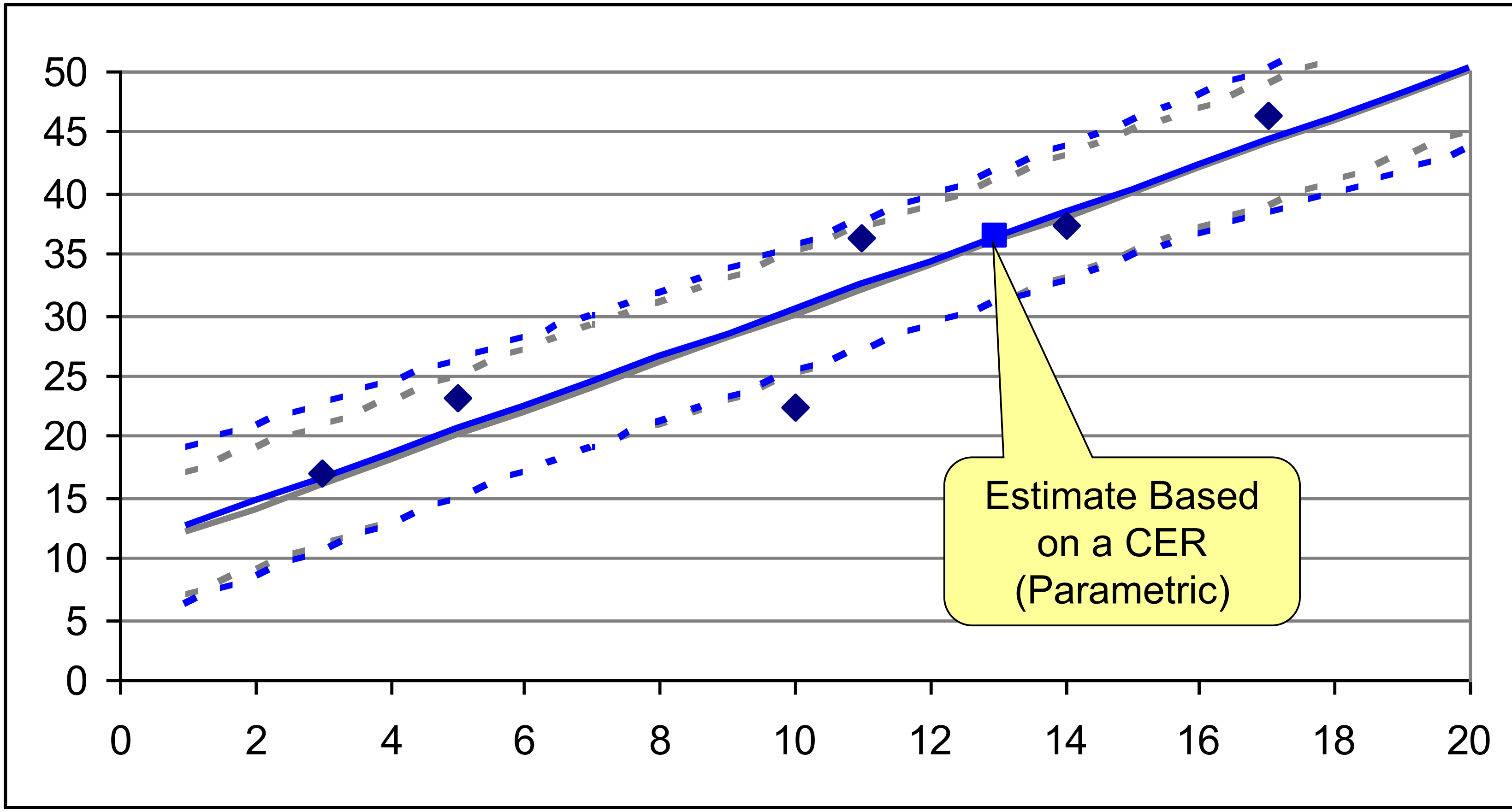
- Uncertainty
  - Uncertainty in intercept and slope of regression line
    - Standard error → Confidence Interval (CI)
  - Uncertainty in distribution around regression line
    - SEE → Prediction Interval (PI)
- Risk
  - Risks not "included" in historical data set
  - Historical growth of cost driver(s)

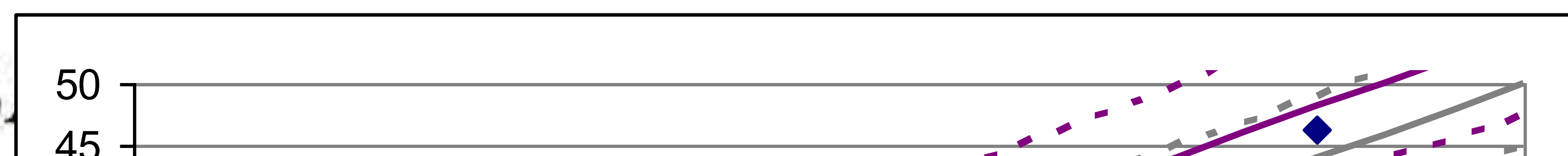
"bounce" and "wiggle"

"fuzz" or "noise"

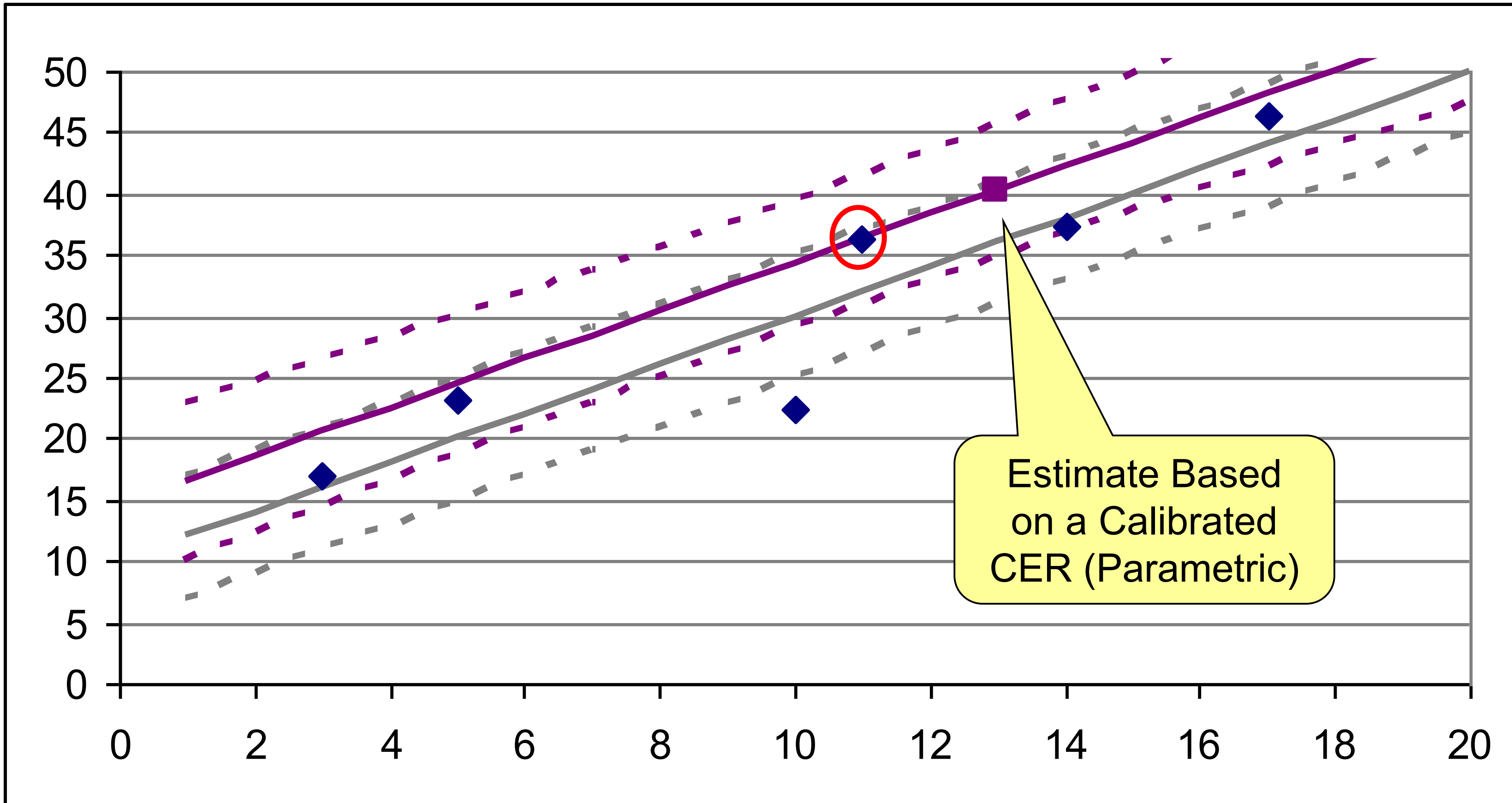
Tip: Parametric has the strength of using statistical results to capture the uncertainty in estimating beyond the range of the data

Parametric - Uncertainty/Risk Illustration





Parametric - Uncertainty/Risk Illustration



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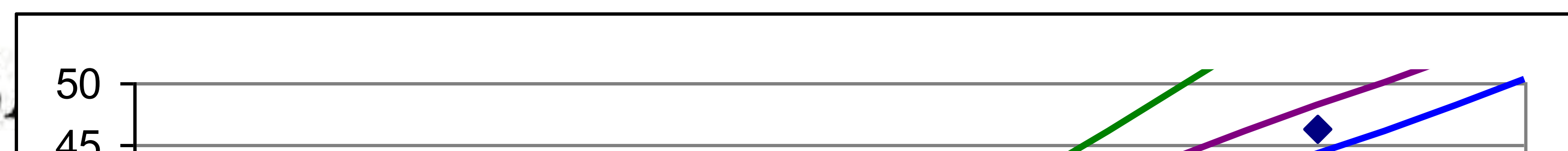

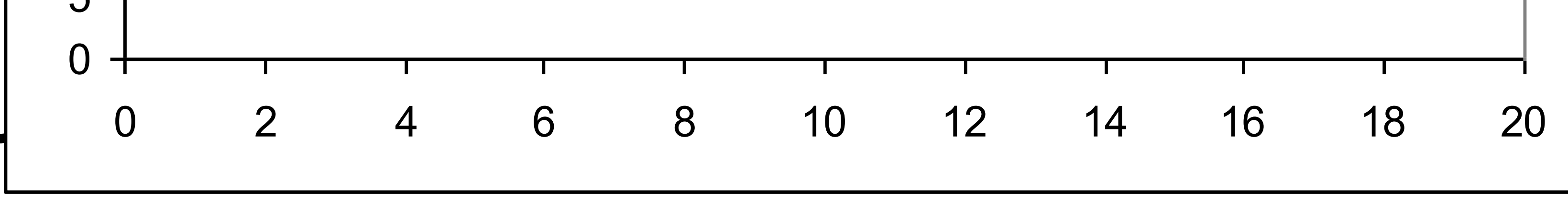
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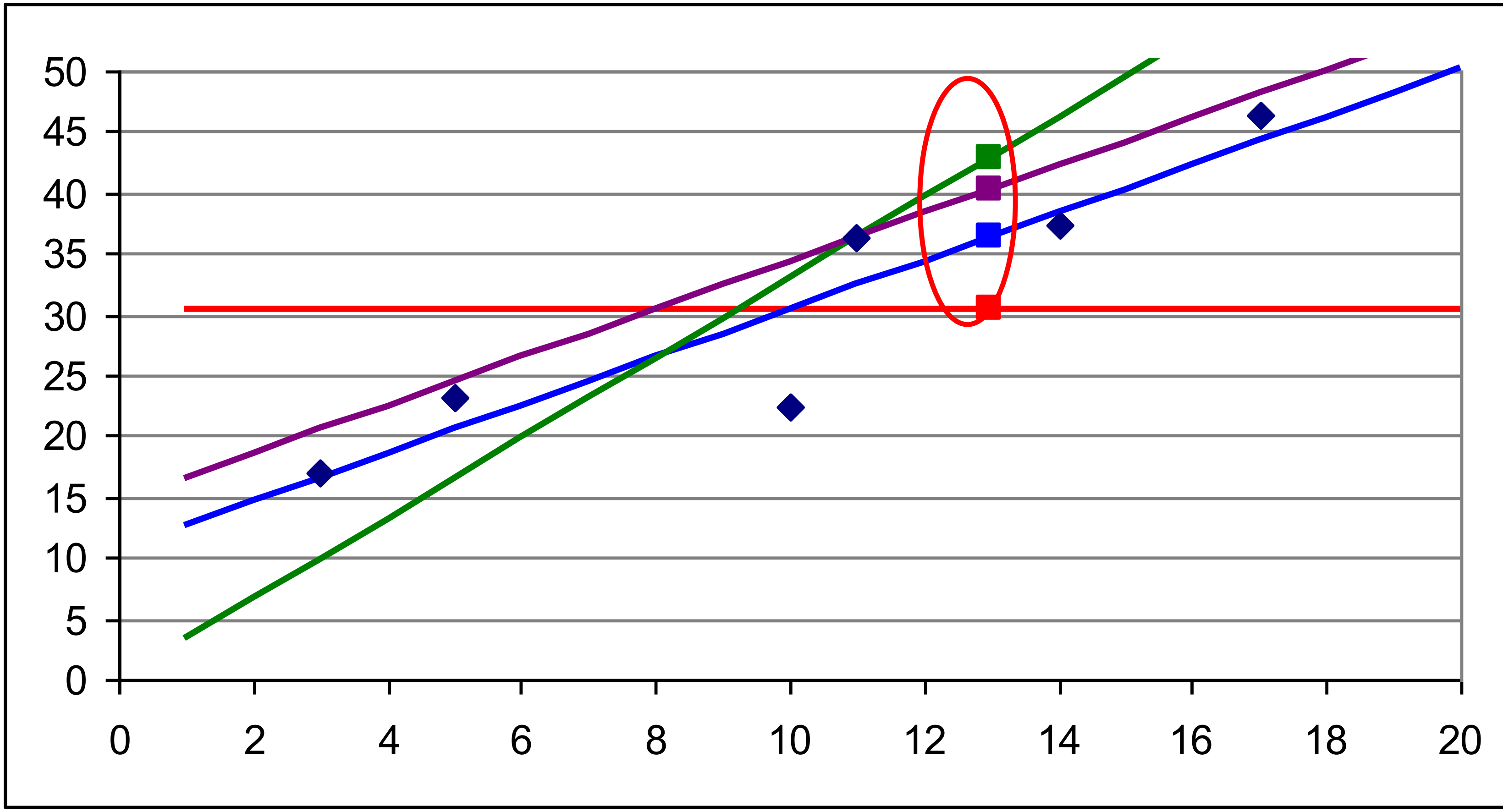
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Build-Up - Method

- 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

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

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

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- 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

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

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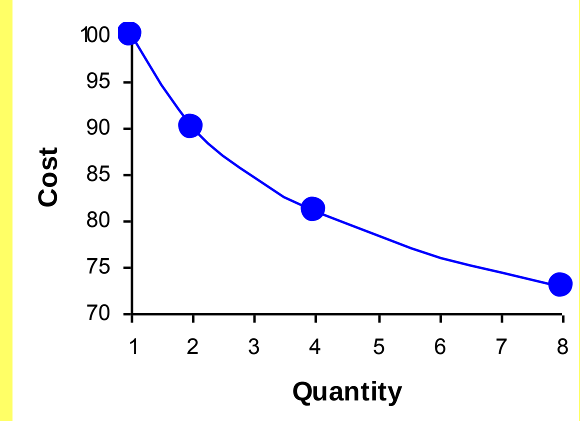

"Stay the course"

2

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

Extrapolation from Actuals - Application

- 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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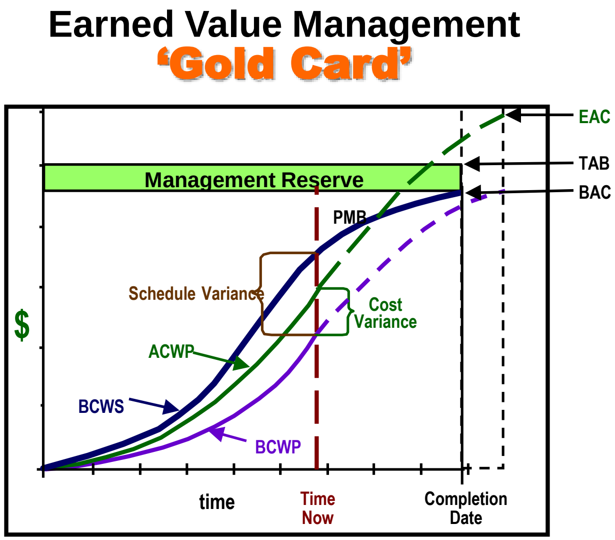

Tip: Improved integration between the cost estimating and earned value functions has lead to increased prevalence of this estimating method

Extrapolation from Actuals – Considerations

- 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

- 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

Expert Opinion

Expert Opinion - Method

- 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

Expert Opinion - Application

- 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.

Expert Opinion – Considerations

- 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

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

Using Cost Estimating Techniques

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

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

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}

Cost Element Structure

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- 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

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

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.

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!

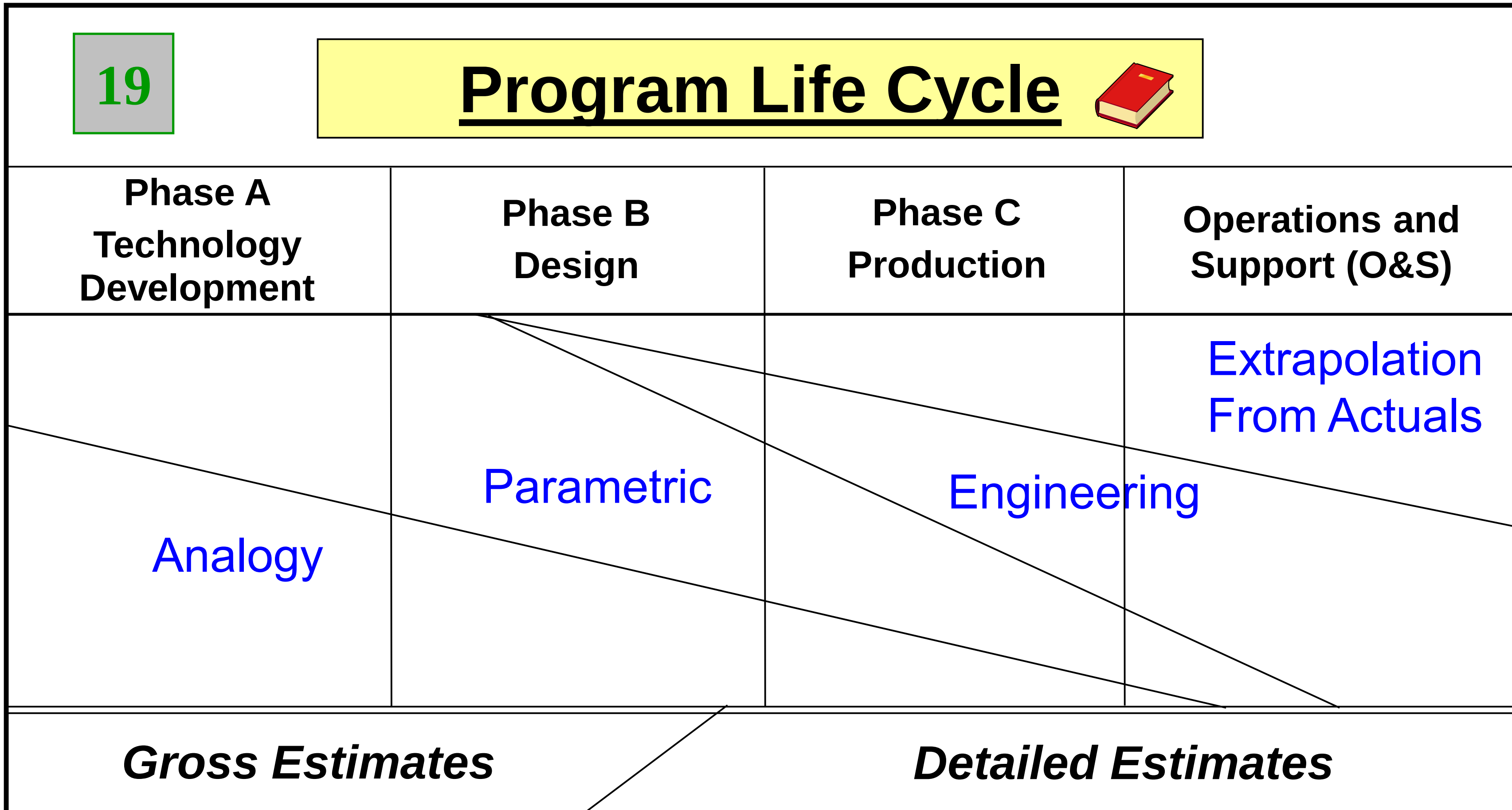
Comparison of Techniques

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!

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

- 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

- 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

Related and Advanced Topics

- Analogies and Rates
- Below-The-Line (BTL) Factors
- Schedule Estimating
- Operations and Support (O&S) estimating

Analogies and Rates

- Analogy scaling can be expressed as a rate
  - Such rates are common in certain circles
    - $/lb, mhrs/ton, mhrs/LOC, etc.
    - Reciprocal = productivity (e.g., LOC/mhr)
- Mathematically equivalent:
  - $5.2M/12,000 lbs = $433/lb of thrust
  - $433/lb x 16,000 lbs = $6.9M
- Same concerns as with adjusted analogy
  - Prefer regression-based CER, when possible

Below-The-Line (BTL) Factors

- Typically Systems Engineering, Integration and Test, and Program Management (SEITPM)

AKA "Cost-on-Cost" CERs

- Often a function of Prime Mission Equipment (PME)

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- Beware non-statistically-based factors
- Similar in application to burdens like Overhead and G&A, but less "deterministic"

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- Should be modeled using Functional Correlation in the risk model

Below-The-Line Factor Example

- SEITPM for a space system
  - Historically 20% of PME
- Prime Mission Equipment (PME):
  - Hardware cost + Software cost = $2M
- The estimate for SEITPM is:

$$0.2 * \$2M = \$400K$$

- Note: SEITPM may vary based on the historical and current program data

"SE/IT/PM Factor Development Using Trend Analysis", A. Wekluk, N. Menton, ISPA/SCEA, 2007

Schedule Estimating

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- Estimating techniques can also be used to estimate a project schedule (duration)
  - Analogy
  - Parametric
  - Build-up/Extrapolation from Actuals = IMS
- Same considerations hold true for schedule estimating
  - Method
  - Application
  - Strengths, weaknesses, and challenges
  - Uncertainty and risk

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"Best Practices for Project Schedules" (Exposure Draft), GAO-12-120G, 30 May 2012. http://www.gao.gov/products/GAO-12-120G.

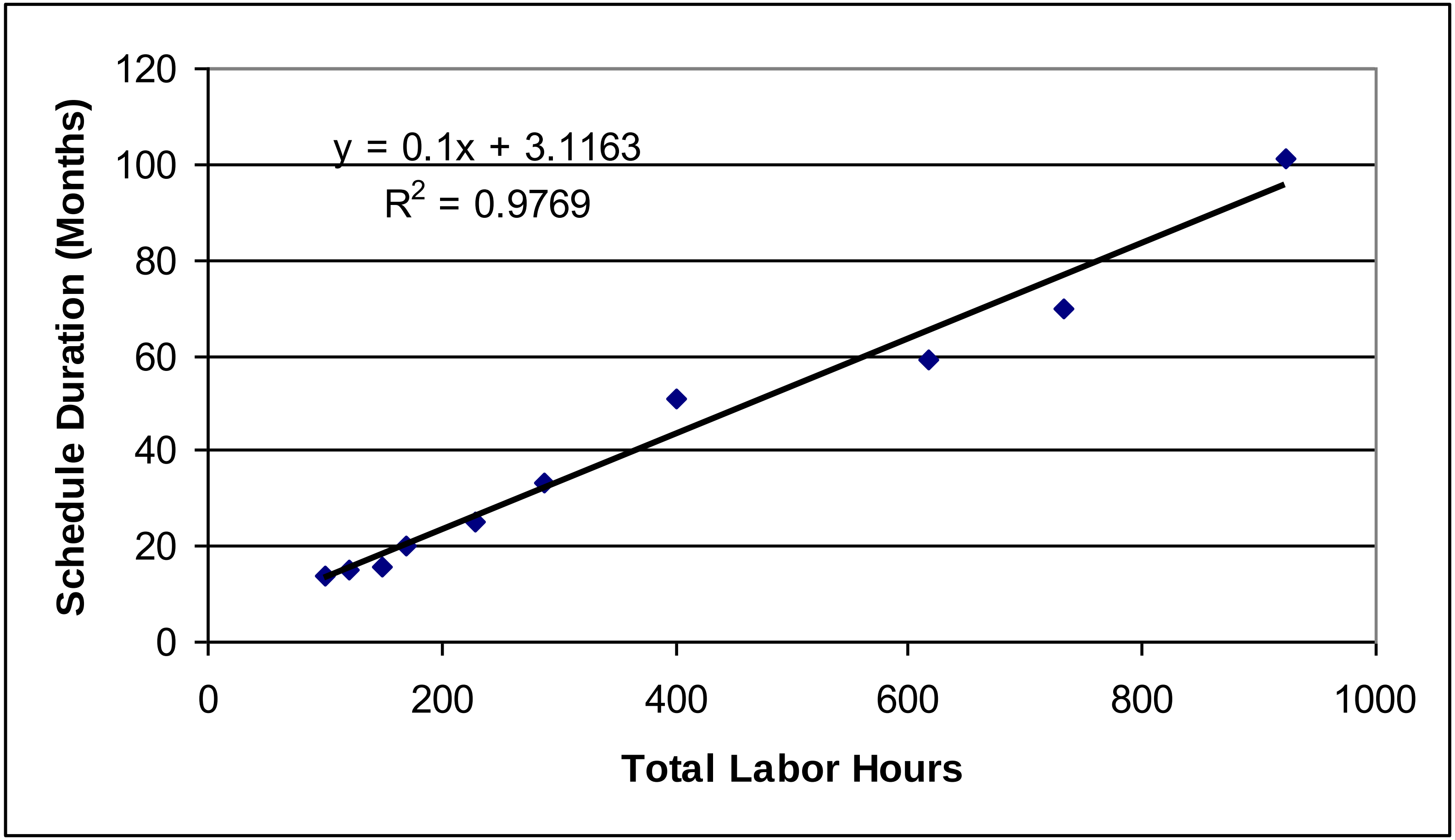
Schedule Estimating - Analogy

- Estimate the integration schedule for a system that is made up of 15 components

	System A	System B
# Components	10	15
Integration Schedule (Months)	40	?

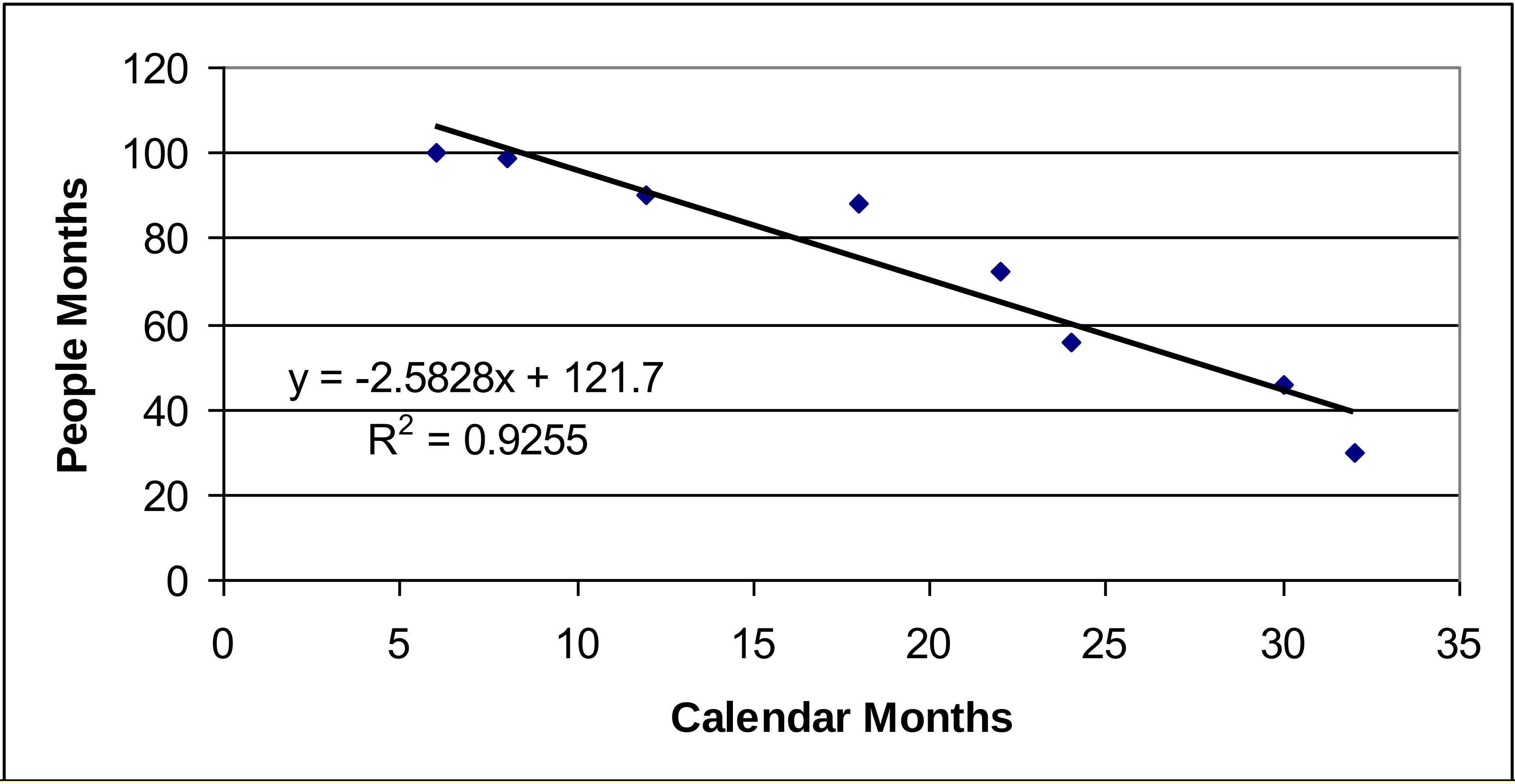
- Based on the completion time from the integration of System A
  - System B integration schedule = (40 months/10 components) * (15 components) = 60 months
    OR
    = 40 months * (15/10) = 60 months

Schedule Estimating – Parametric



Schedule Estimating - Parametric

Constrained Schedule



"The bearing of a child takes nine months, no matter how many women are assigned."
-Fred Brooks, *The Mythical Man-Month: Essays on Software Engineering*

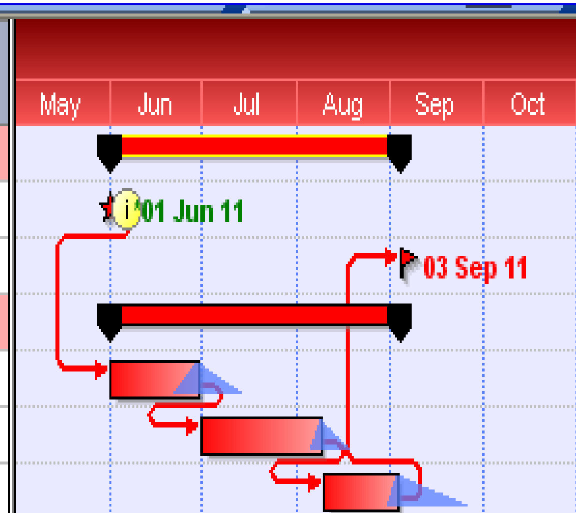
Schedule Estimating - IMS

15

- Estimate of total schedule by rolling-up lower level elements in an Integrated Master Schedule (IMS)
- Requires basis for individual durations
- Beware of deterministic sums for network schedules

9

ID	Description	Remaining Duration	Start	Finish	Task Calendar	Minimum Duration	Most Likely	Maximum Duration
Milestones	Milestones	95	01 Jun 11	03 Sep 11	7 Day			
0010	Start	0	*01 Jun 11		7 Day			
0050	Finish	0		03 Sep 11	7 Day			
Unit 1	Unit 1	95	01 Jun 11	03 Sep 11	7 Day			
0020	Design Uni...	30	01 Jun 11	30 Jun 11	7 Day	20	30	45
0030	Build Unit 1	40	01 Jul 11	09 Aug 11	7 Day	35	40	50
0040	Test Unit 1	25	10 Aug 11	03 Sep 11	7 Day	20	25	50



INT 02 "Advanced Schedule Analysis," David T. Hulett, SCEA/ISPA, 2012.

Operations and Support (O&S) Cost Estimating

- Operations and Support (O&S) costs normally make up a large portion of system life cycle costs and are often overlooked
- O&S costs are defined as all of the costs associated with operating, maintaining, and supporting a system
- O&S costs include costs for:
  - Personnel
  - Consumable and repairable materials
  - Organizational, intermediate, and depot maintenance
    - Hardware *and* Software
  - Facilities
  - Sustainment

AKA Operating and Support (O&S), Operations and Sustainment (O&S), Operations and Maintenance (O&M)

DoD Operating and Support Cost Estimating Guide, OSD CAIG [sic], October, 2007. https://acc.dau.mil/CommunityBrowser.aspx?id=187960.

O&S Cost Estimating - Analogy

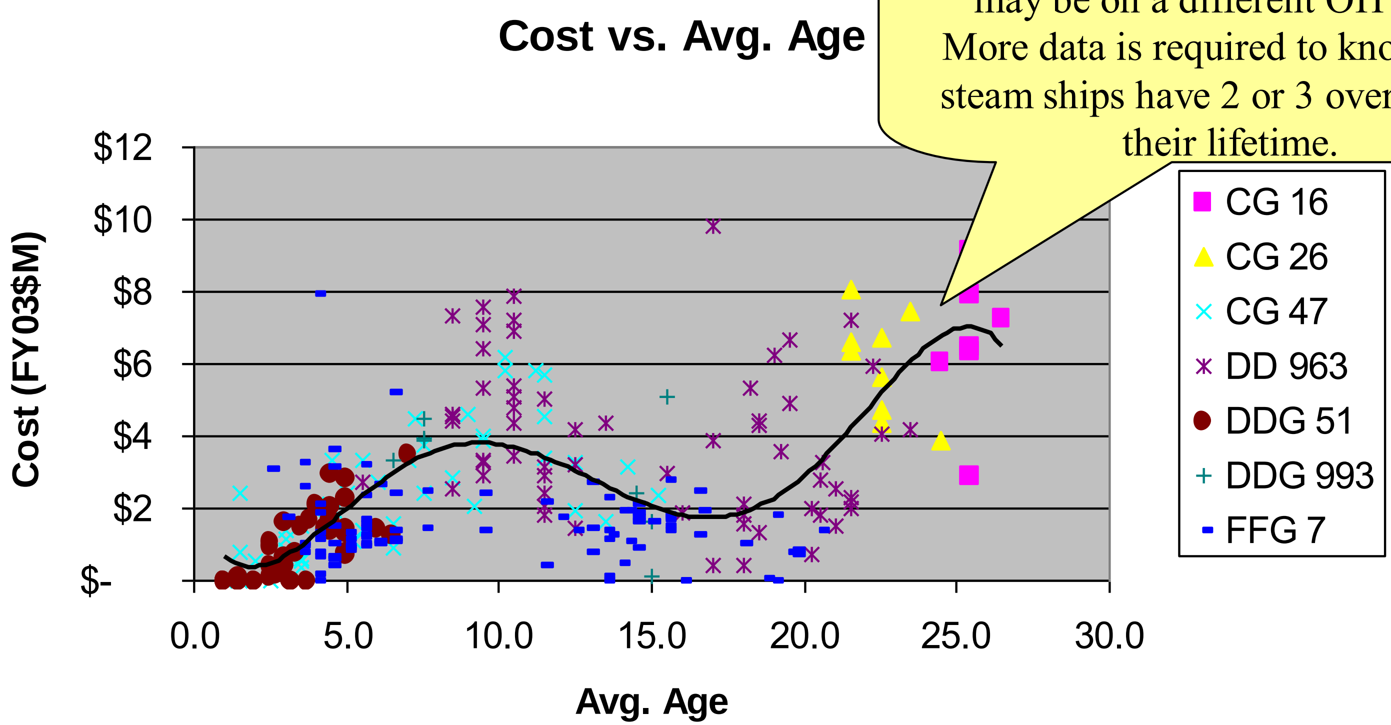
- Annual developed software maintenance cost for the new Ground Processing System (System B) can be estimated based on an analogy of System A

	System A	System B
SLOC	2500000	5000000
Annual Developed SW Maintenance	$ 7,500,000	?

- Based on the Source Lines of Code (SLOC) from System A the developed software maintenance for System B can be calculated as
  - ($7.5M/2.5M) * 5M = $15M
    <u>OR</u>
    ($7.5K) * (5M/2.5M) = $15M

O&S Cost Estimating - Parametric

2nd/3rd overhaul – The steam ships may be on a different OH cycle. More data is required to know if the steam ships have 2 or 3 overhauls in their lifetime.



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"How Age Affects Operations and Support Costs Differently Across Platforms," S. Grinnell, J. Summerville, R. Coleman , SCEA, 2006.

"O&S Physics Based Modeling," Kevin Cincotta, DoDCAS, 2006.

O&S Cost Estimating – Build-up

- Example: reliability-based logistics estimate
- Logistics costs for weapons system broken down into 25 categories
- Bottom-up estimate rolls up costs associated with each of these categories
  - *Some* elements are true build-ups

1. Military Operators
2. Energy (Batteries/Petroleum)
3. Field Support (Material Fielding & Logistics Assistance)
4. Organic Repair Labor
5. Contractor Repair and Other Contractor Logistics Support
6. Warranty Costs
7. Scheduled Maintenance and Overhaul
8. Initial Provisioning Spares
9. Replenishment Spares
10. Inventory Holding Costs
11. Support Equipment
12. Test Program Sets
13. Training
14. Training Material
15. Post Deployment Software Support
16. Technical Documentation
17. Transportation
18. Integrated Material Management
19. Post Production Project Management
20. System Hardware Changes
21. Facilities/Site Activation
22. System Specific Base Operation
23. Leases
24. Demilitarization and Disposal
25. Industrial Readiness