Parametric Analysis Overview

based on the

ISPA Parametric Estimating Handbook (PEH) and

Denver – June 2014

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Parametric Analysis Overview

ICEAA Conference
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- Parametric Advantages
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- Model Building Overview

Parametric Analysis Overview
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What Is Parametric Cost Estimating?

- Parametric estimating is a technique that uses validated relationships between a project’s known technical, programmatic, and cost characteristics and known historical resources consumed during the development, manufacture, modification, deployment, and/or disposal of an end item.

Estimating Methods
Cost Estimating Methods

- Top-down
  - Starts with determination of total program cost. Cost is then allocated downward to functional levels
  - Pros - Quick, best when contract/product details are “sketchy”
  - Cons - Subjective, requires ability to correctly correlate analogous reference to proposed work, requires ability to allocate cost downward

- Bottom-up (grass-roots)
  - Cost estimate at lowest task/process level. Estimates are “rolled-up” into larger summary estimate.
  - Pros - Good audit trail, enhances development of detail “Basis-of-Estimate” (BOE) rationale. Predominate estimating approach.
  - Cons - Very labour intensive, limited responsiveness to changing bid scenarios, very sensitive to estimator bias, prone to “double dipping” and “overlooked”.

- Both methods can utilise multiple estimating techniques

Cost Estimating Techniques

- Analogy
  - Based on historical cost data of similar item and may utilise adjustment factors
  - Involves drawing subjective comparison between two items. Is not detail oriented
  - Most commonly associated with Top-down estimating

- Parametric
  - Based on mathematical relationships between historical costs and other program variables
  - Characterised as Parametrics or CERs
  - Can support either Top-down or Bottom-up estimating
Cost Estimating Techniques

- Detail or Engineering Build-Up
  - Based on a functional level analysis of all tasks, components, processes, and assemblies before estimate is constructed.
  - Most labour intensive estimating technique. Lacks nimbleness to changing requirements
  - Can generate reams of supporting documentation.
  - Commonly associated with Bottom-up Estimating

- Extrapolation from Actuals
  - Trend from current program cost is used to estimate final cost
  - Typically used later in a program when much of the actual cost is known
  - Can support either Top-down or Bottom-up estimating

- Expert Opinion
  - Based solely on individual’s judgment and experience
  - Least labour intensive; Least defensible
  - Typical associated with engineering estimates
  - Can support either Top-down or Bottom-up estimating

Parametric Advantages
Advantages of Parametric Estimating

- Industry and Government representatives recognised parametrics as a practical estimating technique that can produce credible cost or price estimates. Benefits are:
  - Better estimates are provided, often in a matter of minutes;
  - There exists a high-quality, statistically significant and verifiable link between the technical and cost proposals;
  - The data is well understood through the calibration and validation activities;
  - It is much easier to estimate conceptual designs;
  - Early costing cannot be done effectively any other way;
  - No bill of material (BOM) is required;
  - It is much easier to handle scope, technical, and performance changes.

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Parametric Advantage

![Diagram showing the comparison between Parametric Estimating and Detailed Estimating in terms of Quality and Information.](image)

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Today the use of parametric techniques as basis of economic analysis is widely accepted by Industry and Government organizations and growing. Some of the more common applications are:

- Development of independent cost estimates (ICE) (e.g., "sanity checks" on the primary estimating methodology), Rough Order Of Magnitude estimates (ROMs), life cycle cost estimates (LCCEs), and BoE.
- Economic basis for trade studies such as Design-To-Cost (DTC), Cost as An Independent Variable (CAIV), Total Ownership Cost (TOC) and Reduced TOC (RTOC) analyses.
- Parametric techniques are also used to perform cost or price analyses. In fact, the Federal Acquisition Regulation (FAR) identifies parametrics as an acceptable price analysis technique in 15.404-1(b)(2)(iii).
- Basis of Estimate for cost proposals

Parametrics is quick!

Target Budget

Parametric Methodology

Detailed Bottom-up or Grass Roots Methodology

Bid submission date
A Little History –
Parametrics As Basis-of-Estimate (BoE)

- However, in the mid 1990’s using parametric estimating
techniques to develop estimates for proposals was not widely
endorsed. Reasons included:
  - Cultural resistance
    - Many people in the acquisition community (both
      industry and government) expressed greater
      comfort with the more traditional methods of
      estimating
  - Black box mystique of parametric cost models
  - Limited availability of guidance on how to prepare,
evaluate, and negotiate proposals based on
parametric techniques.

- Exploratory meeting - January 1994
  - Determine value of wide-spread use of parametrics for reducing procurement process cost
  - Initiated by HQ DCAA, hosted by Northrop Grumman, Baltimore
  - Participants from DCAA, DCMC, and industry

- Led to a “Barriers to Parametrics Conference” - April 1994
  - General meeting of industry, oversight agencies, and buying commands
  - Hosted by DCAA - Defense Contract Audit Institute, Memphis
  - Identified regulatory and cultural barriers to widespread use of parametric based estimating
  - Executive Steering Committee established to formulate and implement plan to overcome barriers

- Executive co-chairmen
  - Deputy Director DCAA
  - Executive Director DCMC (now DCMA)
  - Controller, then Westinghouse Baltimore

Concerns Regarding Parametrics

- The PCEI identified two general concerns about the use of parametric tools and techniques, and their ability to adequately support cost estimating requirements for contracting proposals;
  - The Truth in Negotiations Act (TINA) data issues seems to be the greatest concern regarding the use of parametric estimating methods.
  - The use of statistical representations of historical data as a basis of forward estimates was a major concern for an estimating culture that developed and reviewed reams of paperwork in a bottoms-up environment.
Reinvention Laboratories Established

- Thirteen Reinvention Laboratories Teams Established

Sponsors

- Commander, Defense Contract Management Command (now DCMA)
- Director, Defense Contract Audit Agency (DCAA)

Objectives

- Identify opportunities for using parametric techniques
- Test parametric techniques on actual proposals submitted to the Government
- Develop case studies based on the best practices and lessons learned
- Establish formal guidance to be used by future teams involved in implementing, evaluating, and/or negotiating parametrically based estimating systems or proposals.

Reinvention Laboratory Teams

- Boeing Aircraft & Missiles Systems
  - St. Louis, MO
- Boeing Information and Communication Systems
  - Seattle, WA
- Boeing Reusable Space Systems
  - Downey, CA
- GE Aircraft Engines
  - Cincinnati, OH
- GE Aircraft Engines
  - Rolling Meadows, IL
- Lockheed Martin Astronautics
  - Denver, CO
- Lockheed Martin Electronics & Missiles
  - Orlando, FL
- Lockheed Martin Electronics & Missiles
  - St. Louis, MO
- Northrop Grumman ESSS
  - Rolling Meadows, IL
- Northrop Grumman ESSS
  - Baltimore, MD
- Northrop Grumman ESSS
  - Rolling Meadows, IL
- Raytheon Systems Company
  - State College, PA
- Raytheon Systems Company
  - Ft. Worth, TX
- Raytheon Systems Company
  - St. Petersburg, FL
- Motorola Space and Systems Technology Group
  - Scottsdale, AZ
- Boeing Aircraft & Missiles Systems
  - Mesa, AZ
Parametric Cost Estimating Initiative Impact

- Addition of Parametric friendly wording to the Federal Acquisition Regulations (FAR)
- Numerous letters of support for parametric based estimating from key DoD procurement executives
- PCEI Newsletter during the reinvention phase which shared best practices and lessons learned
- Parametric Estimating Handbook
  - Identifies parametric principles, calibration and validation requirements, guidelines for evaluation of parametric based BoE.
  - Incorporates lessons learned and best practices from Reinvention Laboratory sites
  - Sponsored by HQ DCAA and maintained by ISPA
  - Now in its fourth revision
- Incorporation of parametric friendly “Instructions To Offerers” in RFPs
- Delivery of numerous presentations at professional estimating conferences

Overview of Parametric Estimating Handbook (PEH)
What Was Changed?
The Parametric Estimating Handbook

- Updated PEH, 4th Edition
  - Published in April 2008
- All chapters experienced extensive rewrite and reorganised
  - “International Use of Parametrics” Chapter
- All chapters edited for clarity, consistent formatting, and modernisation
- Separate set of Appendices
PEH Appendices

- App-A: Model Builders
- App-B: Math of CERs
- APP-C: Frequently Asked Questions
- App-D: Related Web Sites
- App-E: Parametric Estimating Checklists
- App-F: MOU for Parametric Models
- Closure Report
- App-H: SSCAG Risk Summary
- App-I: SSCAG: Non-recurring & Recurring
- App-J: Establishing a Parametric Implementation Team
- App-K: Preparation of Subsystem LevelDatasheets
- Glossary of Definitions

Best Practices of the Parametric Analysis Process

☐ Models have economic value because, properly designed and used, they can:
  ☐ Improve the accuracy of estimates
  ☐ Reduce the likelihood of serious overruns of budgets schedules
  ☐ Reduce the cost of proposals
  ☐ Enable stakeholders to consider more options

☐ Many parametric models also serve to advise on the uncertainties and risks

☐ A model that deals with uncertainty and risk will provide a “range estimate,” also called a probability distribution

☐ Construction and use of valid parametric models is not free
  ☐ Model effectiveness must at least equal its cost
Model Building Overview

Parametric Model Use

- The degree of rigor applied to the use of a parametric model should be no less than that applied to its construction.

- The steps of parametric model use are:
  1. Special setting
     - settings that influence the overall response – like inflation
  2. Model calibration
  3. Parameter values and range
     - enter values for all parameters required
  4. Using the results
What Is The Difference Between Parametrics & CERs

<table>
<thead>
<tr>
<th>Simple Relationships</th>
<th>Complex Relationships</th>
<th>Models</th>
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<tbody>
<tr>
<td></td>
<td>Increasing Complexity of Method/Relationship</td>
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Simple CERs - averages (factors)
Complex CERs – regression based, complexity scalars
Parametric Models – interactive collection of CERs

Parametric Estimating Process

- Parametric estimating is a process
  - Collecting data (cost, schedule, technical, performance, programmatic, and operational) from historical programs
  - Identifying cost drivers
  - Developing Cost Estimating Relationships (CERs)
  - Building a parametric model

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Process – Data Collection

- Collecting data (cost, schedule, technical, etc.) from similar historical programs
  - Corresponding data from current program can be obtained from program cost reports, schedules, and requirements documents
  - Some examples of the types of specific types of data are lines of code, site deployment plans, sub-system procurement, test and evaluation (T&E) schedules, weight, speed, crew size, steaming hours underway (SHU)

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Process – Cost Drivers

- Identifying cost drivers
  - Cost drivers will be the independent variables in your CERs
  - How to identify:
    - Talk to subject matter experts
    - Understand technical and operational parameters
    - Scatterplots

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Cost Drivers vs. Cost Passengers

- Cost drivers are characteristics that drive cost
  - Parameters with greatest leverage on cost – WHY and HOW
  - Identifying usually requires understanding, expertise
  - Most potential for cost savings, may be hard to quantify
  - May include armament, manning, automation, speed, accuracy, reliability, maintenance philosophy, etc.

- Cost passengers are the “big ticket items”
  - Cost elements in WBS with highest values – WHAT and WHERE
  - Can be found with comb charts or Pareto charts
  - Not always the elements with biggest potential for cost savings

CER Development

- The basic idea in CER development is to
  - Identify one or more parameters of a product or project that best explain its cost,
  - Find some historical data that are representative of the desired cost, and appropriately normalise it
  - Identify one or more mathematical functions that “fit” the data
    - Use to estimate future costs based on similar future plans
    - Subject to Best fit
Data Characteristics and Sources

- Cost estimating relationship (CER) is the foundation of the art and science of estimating resource needs in projects using parametric methods.
  - Collection of historical cost data
  - Reducing it to mathematical forms used to estimate similar activities
  - The mathematical forms are called CERs
  - Most commonly algebraic equations
  - Sometimes tabulated data.

Data + Context = Understanding

- Context information such as the following is useful to the CER builder in determining whether or not the future project to be estimated is sufficiently similar to the historical projects from which data was taken:
  - Production quantity
  - Production rate
  - Project schedule
  - Nature of the product
  - Major project perturbations, especially changes in requirements
  - Make versus buy content
  - Special problems or situations encountered, such as introduction of a new technology, major changes in the available skill mix, and so forth.
Data Normalisation

- **Definition**
  - Data normalisation is a process whereby a CER builder attempts to correct for dissimilarities in historical data by putting the data into uniform format.

- **Historical data**
  - Normalisation is virtually always necessary.
  - How much and how fast is data changing
  - Subject to the limitation caused by unrecorded data
  - Normalise for inflation
  - Account for “Learning Curves”

What Output?

- Once data is normalised, the remainder of the development process is highly dependent on the outputs the developer wants the model to produce.
- The most common outputs of commercial models are:
  - Development cost;
  - Development labour hours;
  - Development material cost;
  - Production cost;
  - Production labour hours;
  - Production material cost.
- Which of these cost would be common to hardware and software parametric models?
Data Inconsistency?

What are the best practices with regard to possible data inconsistency?

- Recognise that it can happen, even within the same organisation.
- Within your own organisation, be sure you clearly understand the meanings of the various accounting classifications and how costs are assigned to them.
- Recognise that if data comes from more than one organisation, some cost inconsistency is likely. Ask questions about their ways of treating costs.
- Try to bore down to the actual labour tasks that are done; work with labour hours to the extent possible, not labour costs (e.g., dollars).
- Recognize that even labour hours can have some inconsistency if the skill mix is changing.

Process – CERs

- Developing Cost Estimating Relationships (CERs)
  - After the available historical and industry data are collected for the system, the cost analyst then analyzes “relationships” within the data.

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CERs – Rates, Factors, and Ratios

- Rates: Cost on Parameter
  - Example: The average cost for 1 GB RAID storage is $105 (BY)

- Factors: Cost on Cost
  - Example: System Engineering/ Program Management (SE/PM) = 20% of the program’s prime mission equipment (hardware and software)

- Ratios: Parameter on Parameter
  - Example: 1,200 lines of code to integrate a COTS software package (industry average)

Warning: These three terms are sometimes carelessly used interchangeably.

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CERs – Regression

- A variety of mathematical curves are used. The choice of curve is most often on the basis of some criterion of “best fit.”

- The preferred method for deriving CERs is via regression analysis:
  - Select Variables
  - Test Relationships
  - Perform Regression

- Examples of equations:
  - Linear: \( y = a + bx \)
  - Power: \( y = ax^b \)
  - Logarithmic: \( y = a + b \ln x \)
  - Exponential: \( y = ae^{bx} \)
  - Polynomial: \( y = a + b_1x + b_2x^2 + b_3x^3 + \ldots + b_nx^n \)

- Excerpt from the ICEAA CEBoK®, Unit 1 - Module 3 Parametric Estimating

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CERs – Regression

- The preferred method for deriving CERs is via regression analysis:
  - Select CERs
  - Validate CERs
    - Graphical & Ordinary Least Squares (OLS)
    - Calibration Set vs. Prediction Set
    - Repeat from step 1 as necessary

CER Validation

- CER validation before a CER is used for any risky purpose
- Validation activities are typically:
  - Practical
  - Mathematical
  - Judgmental

*The most practical thing that can be done is to use the CER to estimate one or more projects that have already been completed and see if the answer is consistent with expectations.*
CERs – Calibration

- Calibration: Resetting the y-intercept so that the CER passes through a desired point
- Reasons to calibrate a CER:
  - To provide a borrowed slope for estimating by analogy
  - To make more applicable to a specific subset of data
  - To adjust input factors in a commercial cost model
  - To support CAIV trades more accurately

**Warning:** Never calibrate to a single point in the data set on which the CER is based!

Calibration should always be done with care and with a clear purpose in mind

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Example - Calibrating Parametric CERs

- Tip: A calibrated CER (shifted y-intercept) and an adjusted analogy (borrowed slope) are mathematically equivalent!
Process – Parametric Model

- Building a parametric model
  - After CERs are developed, they are gathered into an integrated, automated structure that makes up the cost analyst’s model for estimating the system

  **Warning:** If you don’t properly account for correlation between cost elements, your uncertainty will be understated!

- Updating the model with actuals
  - After the model is built, the analyst can use actuals to update and re-run the CERs in the model with program-specific data (Risk bounds should account for potential SLOC growth)
    - 1,200 lines of code per package for COTS software integration based on industry data (previous example)
    - 1,500 lines per package based on actuals (update)

- Excerpt from the ICEAA CEBoK®, Unit I - Module 3 Parametric Estimating

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Model Development

The modelling process focuses on the following tasks:

- Specifying the estimating methods for accomplishing the estimating goals;
- Identifying the job functions and other elements of cost that will be estimated;
- Defining data input structures and WBS elements.
Model Validation

Validation is the process, or act, of demonstrating the complex model’s ability to function as a credible estimating tool.

Validation ensures:

- The model is a good predictor of costs;
- Estimating system policies and procedures are established and enforced;
- Key personnel have proper experience and are adequately trained.

Complex Models

- A typical CER uses one, two, three, or perhaps four pieces of parametric information
- A complex model, by contrast, asks for 20 to 40 pieces of information
- Algorithmically robust compared to a CER
- Asks for more information than a CER
- Generally it also provides more information in its output
- CERs often have much wider scope, “rules of thumb” that are broad generalisations
- Complex models are not simplistic, rather they are sufficiently flexible to handle the dynamics of well defined programs
- May incorporate time phasing and inflation
- May provide a range of cost estimates to account for risk and uncertainty
- May incorporate anticipated uses and goals of the analysis into the model logic
  - DTC or CAIV trades, e.g.
How Good Is the Estimate?

- Project managers and others frequently challenge results from parametric models, especially when:
  - They appear to run counter to their expectations
  - When their management is called into question for overrunning an estimate by the GAO or Congress

- Parametric estimates are not necessarily “Wrong”
  - Rather, the system has a built-in bias against overruns
  - And a bias for competition that drives down costs

- Will the biases in our political system ever understand when an estimate is “Right”?

What To Do With The Results?

There is no point going to all this trouble if you don’t do something with the output of a parametric model AND quickly...

Applications of parametric are:
- Proposal pricing
- Rough estimates
- Trade studies
- Active project management
- Sanity checks and cost realism
- Competitive analysis
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