A Parameter Driven World

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Here are some definitions of **Parametric Cost Estimating** from various sources.

From the Project Management Body of Knowledge [3] (PMBOK):

Parametric Cost Estimating is an estimating technique that uses a statistical relationship between historical cost data and "other variables" (for example, square footage in construction, lines of code in software development) to calculate estimates for activities.

From NASA (two definitions):

Definition 1) A mathematical procedure where product or service descriptors (parameters or independent variables) and cost algorithms directly yield consistent cost information

Definition 2) Mathematical representation of Cost Estimating Relationships that provides a logical and predictable correlation between the physical or functional characteristics of a system, and the resultant cost of the system

From the Department of Defense:

Parametric estimating is a method by which aggregated costs are derived as a function of high-level product characteristics or parameters. The resulting equations are known as Cost Estimating Relationships (CERs).

A **parameter** is a characteristic, feature, or measurable factor that defines a product or program.

It can be a quantitative measurement / characteristic, such as: Weight, Capacity, or Speed.

It can be a qualitative or categorical characteristic. Here are examples of qualitative parameters:

a. Simple, Average, Complex
b. Navy, Air Force, Army
c. Unmanned, Manned
d. Programming Language: JAVA, C++, etc

The "Shall" statements on a systems requirements document often contain parameters.

Parametric analysis is used to develop mathematical relationships between parameters and program costs (for material, labor, licensing costs, etc)

Here are some examples of parameters.

Parameters in the IT world:

- Quantity of servers / hard drives
- Quantity of desktop computers
- Quantity of laptop computers
- Specifications of hardware
  - Capacity
  - Speed
  - RAM
  - Range
  - Operating System
- Level of Security
- Number of interfaces
- Communication requirements
- Lines of Code
- Programming language
- Number of Licenses
- Number of Users
- Number of Web Pages
- Number of records

Parameters in the aerospace world:

- Max speed
- Weight / material breakdown
- Range
- Flight envelope / missions / stores
- Manned vehicle / unmanned vehicle
- Type of engine(s) / envelope for engine(s)
- Interfaces / communication requirements
- Envelopes for subsystems / black boxes
- Observability
- Special requirements
- Level of Security
- Quantity of aircraft
- Number of Drawings

In the future, parametric analysis will go way beyond just cost estimating. It will be used in every aspect of planning and performing work. As computer technology advances, humans will choose the parameters, and then computers will take over to a greater and greater extent. Currently we are able to have computers generate estimates and cost proposals based on parametric information. Within a decade or so, computers will be able to do much of the project planning and project management. Within a few more decades, computers will be able to generate a design based on the parameters. And a few decades after that, computers and robotic equipment will be able to take over most aspects of production.

Jobs for humans will become scarcer. Computers and robots will do the bulk of the work.

Parametric Cost Estimating

A properly developed and maintained parametric cost estimating system should provide more accurate and supportable contractor estimates, lower cost proposal processes, and more cost-effective estimating systems. Many companies need to improve the way cost information is collected with “other data”. The “other data” is often lost or forgotten.

In the past, parametric estimating has been viewed with some skepticism, but it is gaining acceptance. It will eventually be the preferred estimating methodology.

Here are some examples of estimating methodologies ranked in the order of preference:

1. Analogous or based on actual or quoted costs – actual history for a similar task or factored with justification

2. Standard time or labor standards (backed up with time studies) with learning curve included
3. Parametric - historical relationships to non-cost parameters calibrated and adjusted for complexity
4. Cost Estimating Relationships (CERs), for example percent to factory touch labor
5. Level of Effort (LOE) compared to a similar project or a previous time period
6. Judgment / expert opinion / grassroots

The Cost Estimating Body of Knowledge [2] (CEBoK) contains a module on Parametric Estimating. This module provides an overview of parametrics. It covers the process of building parametric models and describes how those models are used. The module discusses cost estimating relationships (CERs) and introduces the topics of data use, CER development, and development of complex models. The proper development and application of CERs depends on understanding the associated mathematical and statistical techniques. This module provides general guidance for use in developing and employing valid CERs, including differences between simple and complex CERs, techniques for developing and implementing CERs, including linear regression ordinary least squares (OLS) "best-fit" models. It also examines current "Off the Shelf" models and development tools such as PRICE, SEER, COCOMO II, and ACE-IT and their particular applications.

Also, there is a Parametric Estimating Handbook [1], originally published by the International Society of Parametric Analysts (ISPA). This handbook describes parametric techniques to collect historical cost data (or labor hours) and the associated non-cost data which describes the physical, performance, and engineering characteristics that influenced those costs. Data should be collected and maintained with an audit trail. Historical cost data may need to be normalized or adjusted to account for differences related to scope of work, program anomalies, changes in technology, new business practices, inflation, learning curve and quantities, and production rate. Non-recurring and recurring costs should be separately identified.

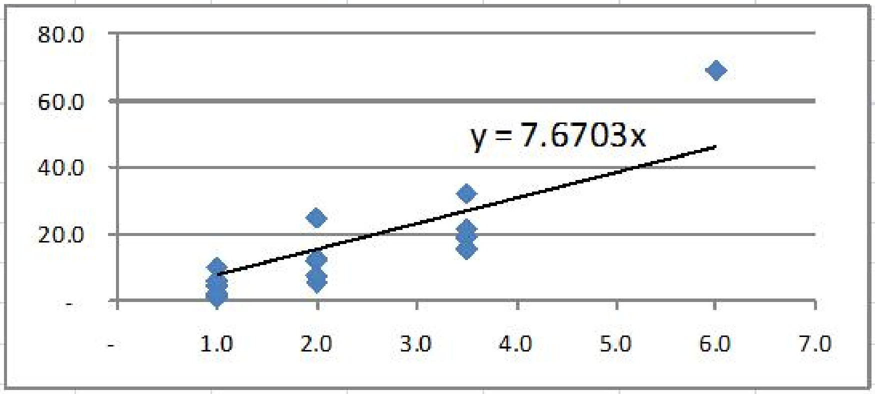
With a properly developed parametric cost estimating system, after the input parameters are selected and estimated, the output will include time-phased nonrecurring and recurring cost estimates for the following categories:

- Development labor
- Support labor
- Manufacturing / Tooling
- Hardware / Spares
- Software (initial and annual costs)
- Travel / Shipping

Ideally, the system will provide supporting rationale (BOEs) and the framework for the Cost Management Plan. This is already happening at some companies. Some companies do not have sufficient data to use a parametric estimating approach and the transition to parametric estimating is difficult. Many companies use off-the-shelf cost models (PRICE, SEER, etc.) to generate their cost estimates.

REGRESSION OUTPUT

Regression Statistics	
Multiple R	0.9209
R Square	0.8481
Adjusted R Square	0.7856
Standard Error	8.8153
Observations	17



ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6942.4	6942.4	89.3371	0.0000001
Residual	16	1243.4	77.7		
Total	17	8185.8			

	Coefficients	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0					
X Variable	7.6703	0.8115	9.4518	0.0000	5.9500	9.3907
	Y = 7.67 X					

Figure 1: A parametric estimating example with one independent variable (complexity) in which values for the independent variable have been assigned as follows; simple=1, average=2, above average=3.5, complex=6

There are pros and cons of parametric cost estimating. Here are some pros:

- Faster estimating process
- More accurate estimates
- Better substantiation (less subjective)
- Smaller negotiation decrements (if there is agreement on complexity)
- Easily adjusted as parameters change
- Faster negotiations
- Faster budget release

Here are some cons:

- Less flexible estimates, less negotiating room
- Estimates are at a higher level, less visibility at lower levels
- Judgment on complexity will be the point of contention (if complexity is one of the independent variables)
- Significant difference in estimate with a next up/down change in complexity
- Customer (or Management) reaction unknown
- Customer may demand to see the underlying data and that may give them more to pick at
- Customer may not fully understand the methodology and be skeptical

- Expectations may be raised (for future proposals). It may be difficult to go back to the old way. Once your customers know that you have a parametric cost model, they will want to see its output on all future proposals.
- Insufficient historical data on a key parameter (a new technology)

Aversion to any of the “Cons” causes many companies to be wary of parametric estimating.

DFARS 215.4 and 215.8 require all DOD contractors to have acceptable estimating systems, and certain large businesses to disclose their estimating systems in writing, provide guidelines concerning the characteristics of an acceptable estimating system, and provide guidance for team estimating system reviews. If a contractor is required to disclose their system, all significant parametric cost estimating techniques need to be disclosed.

Acceptable estimating system means:

1) Is maintained, reliable, and consistently applied
2) Produces verifiable, supportable, documented, and timely cost estimates that are an acceptable basis for negotiation of fair and reasonable prices
3) Is consistent with and integrated with the Contractor’s related management systems
4) Is subject to applicable financial control systems

When analyzing proposals from contractors, the Government may use various price analysis techniques including parametric estimating to ensure a fair and reasonable price.

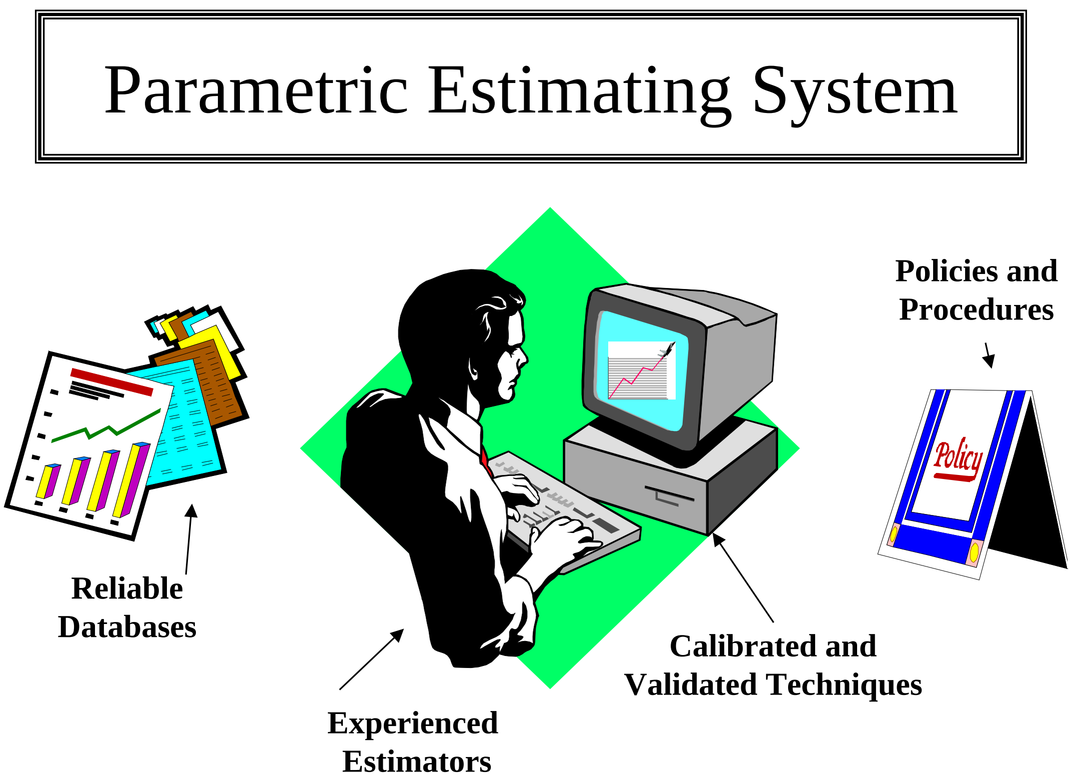
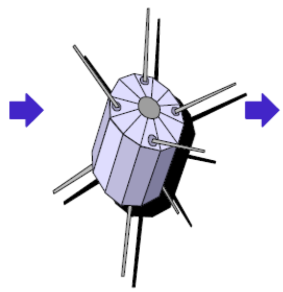


Figure 2: Graphic from the Parametric Estimating Handbook showing the elements of a Parametric Estimating System

Hardware Modeling

A Hardware Model Uses Common Parameters
To Estimate and Evaluate New Requirements

- Input Parameters
  - Magnitude (quantity)
  - Operating environment
  - Amount of new design & design repeat
  - Engineering complexity
  - Manufacturing complexity
  - Schedule
  - H/W - S/W integration
  - Weight / volume



- Output Parameters
  - Cost
    - Development
    - Production
    - Engineering
    - Manufacturing
  - Schedule risks
  - Unit /system integration costs

Figure 5.1 Hardware Model Input and Output Parameters

Figure 3: Excerpt from the Parametric Estimating Handbook

These are the steps needed to start a parametric estimating database:

- Locate cost / labor data
- Copy data to a master spreadsheet
- Verify data (accuracy / completeness)
- Organize / categorize / sort data
- Select / exclude data (outliers)
- Locate non-cost parametric data (such as the Input Parameters in Figure 3 above)
- Align cost / labor data to non-cost parameters
- Analyze / perform regression analysis / develop relationships
- Develop the model
  - Set the input format for the parametric data
  - Set up the internal equations
  - Set the output format, which can flow directly into the Basis of Estimate (BOE)
- Test / calibrate model
- Document procedures
- Use model for estimating

The key is to a good parametric estimating system is to capture cost and parametric data upon closeout of each significant contract period (each project / each phase / or each change that is separately tracked).

These are the steps needed to maintain a parametric estimating database:

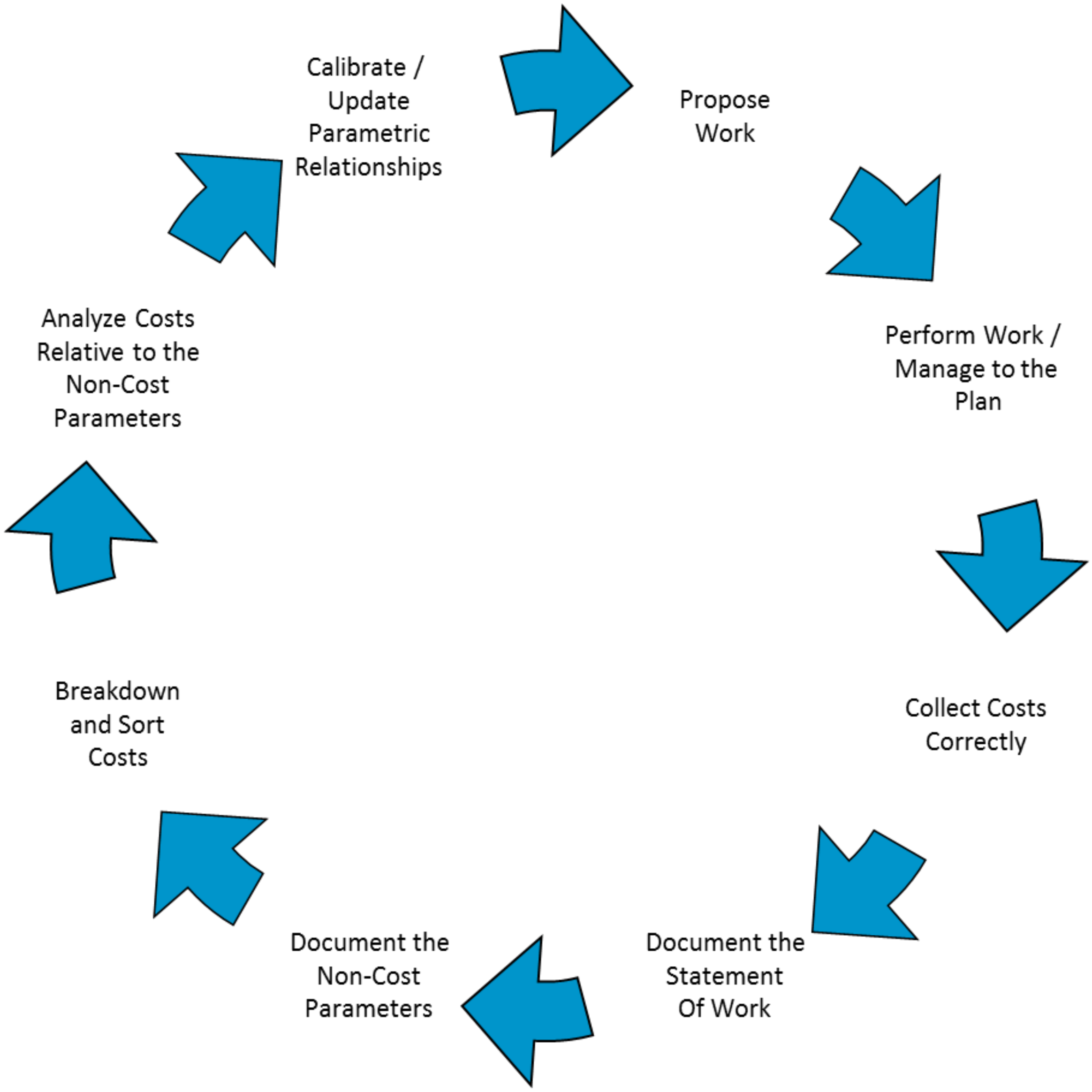


Figure 4: Steps needed to maintain an estimating database

Three things make a good parameter (independent variable):

1. Must be quantifiable
   - A quantitative parameter (such as weight)
   - A qualitative parameter which is converted to a quantitative value
   - Simple = 1, Average = 2, Complex = 4
2. Good correlation to the dependent variable, either positive or negative
   - Positive correlation
     - When the parameter increases, the dependent variable increases
     - When the parameter decreases, the dependent variable decreases
   - Negative correlation
     - When the parameter increases, the dependent variable decreases
     - When the parameter decreases, the dependent variable increases

3. The value is known or can be estimated accurately up front (at the time the estimate is made)
    - Do not use a parameter if its value is as uncertain as the dependent variable it is trying to estimate
        - For example, using SLOC (if you haven't a clue what the number is) to estimate software programming hours

You can convert qualitative parameters to quantitative values by assigning values which correlate with the dependent variable.

- Example 1) If data suggests that an average item is twice as costly to produce as a simple item, and a complex item is twice as costly as an average item, then assign values as follows: Simple = 1, Average = 2, Complex = 4
- Example 2) If data suggests that programming time for a C++ project is twice as much per line of code than for a JAVA projects, then assign complexity values as follows: C++ = 2, JAVA = 1

If an important qualitative parameter cannot be converted to quantitative values, you must analyze the data for each category of that parameter separately.

Parametric Affordability Improvement

Parametric analysis can be used to improve affordability. The key to affordability is gaining parametric control over touch labor, support labor, material and supplier costs.

"Parametric control" is knowing what things should cost.

Use parametric analysis to right size / right cost all labor functions and supplier costs.

Affordability starts by finding out what things and tasks should cost (with optimal processes). To do this, you need to develop cost models / databases. Compare "should cost" to what things / tasks are actually costing. If actual costs are higher than what they should, figure out what needs to be done to get to the "should cost". Estimate nonrecurring costs to implement the change. Estimate the recurring savings (between "should cost" and current actuals). Calculate ROI (= future savings / NR cost). Get program management approval to make the change. Make the change.

The more parametric analysis you do to figure out what things should cost, the more opportunities you will find.

For touch labor, start by measuring / monitoring work content on a regular basis. Use an industrial engineering technique such as Time Study, Methods Time Measurement (MTM), or Random Time Observation Analysis (RTOA). Develop accurate parametric standards for basic tasks: installing a computer, updating an operating system, replacing a hard drive, etc. When employees know there is accurate measurement, they will not sandbag. What gets measured, gets done. What gets measured, gets improved. There will be increased motivation for process improvements.

For support labor, it's the same idea. Use industrial engineering techniques. Determine the parameters which drive the work. Determine which tasks are necessary to get the job done. Develop metrics for major tasks for all support functions. Interview workers. Collect parametric data (labor hours and parameters). Develop parametric standards for tasks (the work content). Develop improvement curves - support labor improvement curves are typically steeper than touch labor. Staff to the right size. Implement an earned value management system. When employees know there is accurate measurement, they will not sandbag. What gets measured, gets done. What gets measured, gets improved. There will be increased motivation for process improvements.

To figure out what the parameters are for support labor, you have to ask the right questions:

- What are the main categories of work in your function (the main tasks / things you do)?
- What are the outputs (drawings, reports, purchase orders) ?
- What are the inputs (change requests, purchase orders) ?
- What drives the amount of work for each of your tasks (what are the parameters) ?
    - Quantitative drivers (number of parts, number of drawings, number of interfaces, lines of code)
    - Categorical drivers (complexity, programming language)
- How long does it take to do task A if the parameters are XYZ ?
- How much more (less) if parameter X is changed ?
- Here is some historical data for a completed task. Could you please describe the parameters that were associated with this task ?

For hardware costs follow this process:

- Figure out the parameters that drive costs
    - Material type (aluminum, titanium, composite)
    - Material form (plate, forging, sheet)
    - Weight
        - Raw material weight
        - Finished weight
    - Complexity (simple=1, average=2, above average=3.5, complex=6) or perhaps surface area is a better parameter to use, to avoid subjectivity
    - Manufacturing process (high speed machining, sheet metal fab, handlay)
    - Additional finishing process (heat treat, anodize)
    - Lot quantity and cum unit number
    - Labor rates
    - Raw material cost per pound

- Put all the data on a spreadsheet

Part Number	Part Cost (Labor Portion)	Part Cost (Material Portion)	Material Type	Material Form	Raw Material Weight	Finished Weight	Complexity	Manufacturing Process	Additional Finishing Process	Lot Quantity	Labor Rate	Raw Material Cost Per Pound

Figure 5: Spreadsheet to record parametric information related to parts costs

- Develop a parametric model for estimating “should cost” of parts based on the parameters – you’ll have to do a lot of regression analysis
- Develop a parametric model for cost of changes to parts
    - Nonrecurring impact (the cost to make the change)
    - Recurring impact (the delta cost per part for all future parts)
- Data is available to develop these models, you just have to dig for it
- Major contractors need a parametric estimating model for parts costs for effective negotiations with suppliers, otherwise the suppliers have the advantage
    - Keep up with state-of-the-art technologies (i.e. for optimal cutting speed)
- Select suppliers who are improving equipment / technology

Here are some tips for developing a database for parts costs:

- Use analysis techniques to develop an estimating model for parts
- Calculate the raw material cost for a part
    - Raw material weight x cost per pound
- Calculate the processing costs (labor cost)
    - Note: only use data from the most efficient suppliers
    - Separate the labor into these categories
        - Basic processing:
            - Machining time (can be calculated using material removal rate)
            - Non-machining time (loading, unloading, cutter changes, etc.)
            - Setup (setup time / lot size = setup per part)
        - Additional finishing processes (if any)
        - Additional sub-assembly (if any)
        - If labor data not available, estimate (using industrial engineering techniques or reverse engineer)
    - Use analysis techniques to develop an estimating model for the labor cost
        - Use regression analysis: labor vs. parametric factors (weight, complexity, etc.)
        - Labor cost per part = hours x labor rate
- Cost per part = raw material cost + processing costs

After you've developed a parametric cost model for hardware costs, run all your parts through the model and you will find the affordability opportunities.

References:

1) Parametric Estimating Handbook **http://www.galorath.com/images/uploads/ISPA_PEH_4th_ed_Final.pdf**

2) Cost Estimating Body of Knowledge (CEBoK) **http://www.iceaaonline.com/cebok/**

3) Project Management Body of Knowledge (PMBOK) **http://www.pmi.org/PMBOK-Guide-and-Standards.aspx**