Parametric Estimating

From data to CERs

"Parametric estimating is a technique that develops cost estimates based upon the examination and validation of the relationships which exist between a project's technical, programmatic, and cost characteristics as well as the resources consumed during its development, manufacture, maintenance, and/or modification."
-Parametric Estimating Handbook

Parametric Estimating Handbook (4th ed.), ISPA, 2008.

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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3. *Parametric Estimating*

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Unit V – Management Applications

Parametric Estimating Overview

- Key Ideas
  - Cost Drivers (and "Cost Passengers")
  - Inputs and Outputs
  - Parametric Models
- Practical Applications
  - CER Development
  - Cost Response Curves (CRCs)
  - Sensitivity Analysis
  - Schedule or Weight Estimating Relationships
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    - Power, exponential, log, polynomial
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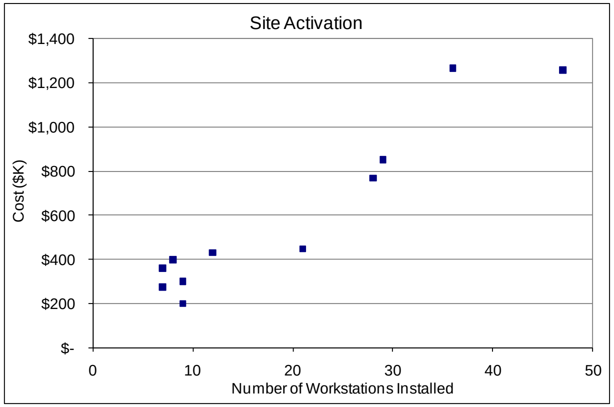
Parametric Estimating Within The Cost Estimating Framework

v1.2

Past

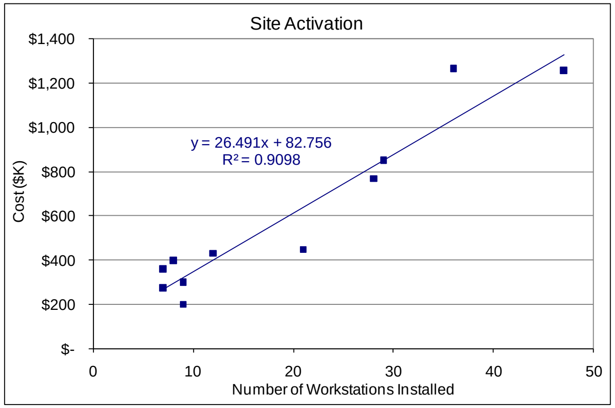
Understanding your historical data



Historical costs for similar systems

Present

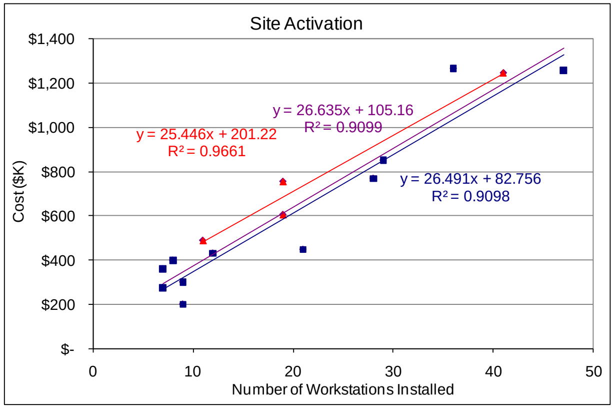
Developing estimating tools



Cost Estimating Relationships

Future

Estimating the new system



Calibrating, Applying, Validating, and Updating CERs

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Parametric Estimating Outline

- Core Knowledge
  - Basics of Parametric Estimating
  - Parametric Estimating Process
    - Collecting data
    - Identifying cost drivers
    - Developing CERs
    - Building a parametric model
  - Parametric Estimating Examples
- Summary
- Resources
- Related and Advanced Topics

Parametric Estimating Technique

- Parametric Estimating - The process of using cost estimating relationships (CERs)[1] based on historical data to estimate a project's cost

3

- Identifies cost drivers to estimate cost and schedule
  - Technical parameters, like size and weight
  - Performance parameters, like speed and accuracy
  - Programmatic and Operational parameters, like quantity

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- Strengths
  - Model is easily traceable and objective
  - Can be easily adjusted for changes to the system or sub-system by modifying input parameters
    - Important for sensitivity analysis and design trades
  - Statistical results relating to the model
    - Includes t statistics, F statistics, R^2, coefficient of variation (CV)
    - Objective measures of validity
    - Used in risk analysis

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Tip: Many cost estimators confuse parametric estimating with the use of COTS models. Most COTS cost models are parametric, but many parametric models are not COTS.

1 - CER is defined as an equation relating cost to one or more cost-driving variables

Cost Estimating Techniques

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Technique	Approach	Considerations
Analogy	Comparative analysis of similar systems	Can be used early in programs before detailed requirements are known, but there is no objective test of validity
Parametric Estimating	A mathematical relationship between parameter(s) and a cost	Historical data is difficult to obtain, but CERs can be easily adjusted for requirements changes and provide statistical results
Engineering Build-Up	Estimating is done at lower levels and results rolled up to produce higher-level estimates	It is easy to see exactly what the estimate includes, but it is expensive and requires detailed data to be collected, maintained and analyzed
Extrapolation from Actuals	The 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

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Tip: Many estimators distinguish between CERs, which are taken to be Parametric, and Analogy or Build-Up, but this distinction is not universal.

Parametric Estimating and the Life Cycle

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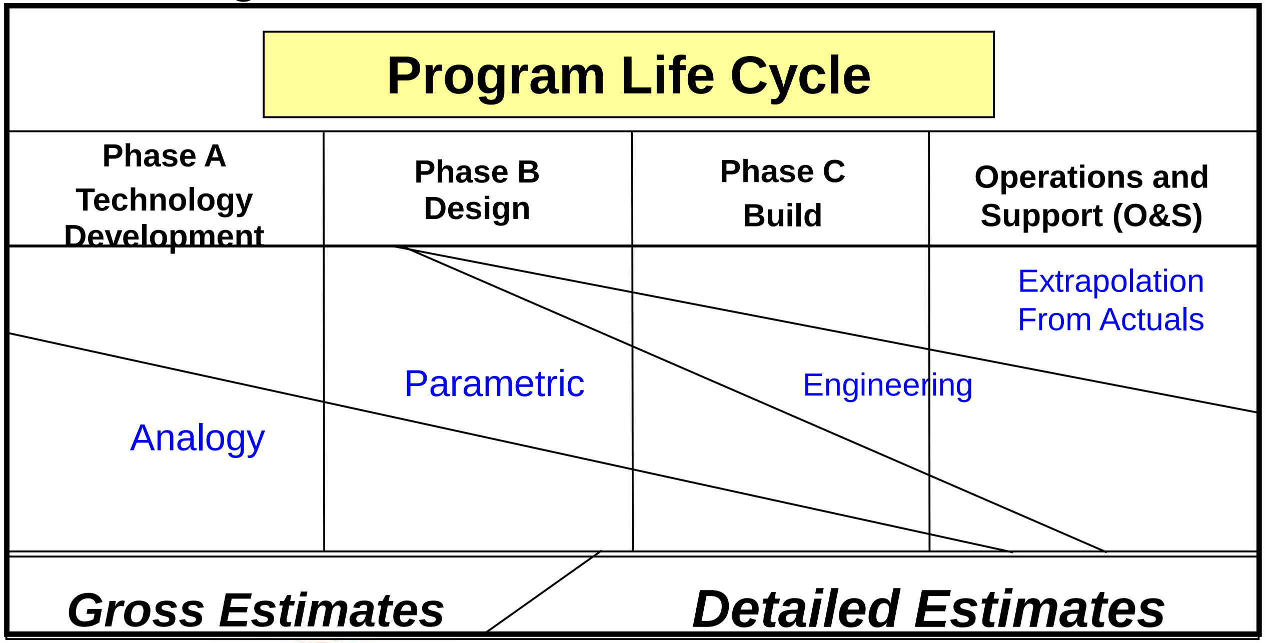
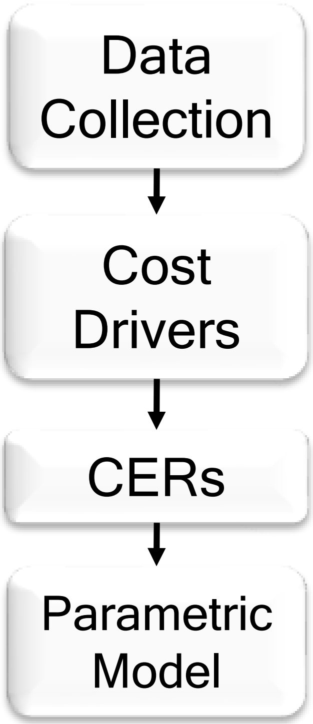
- Different techniques are used for the different stages in the acquisition/product development cycle
  - Early in the program, cost estimates are based predominantly on analogies and parametrics
  - As the program matures, the estimate will incorporate greater amounts of actuals



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

Parametric Estimating Process



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

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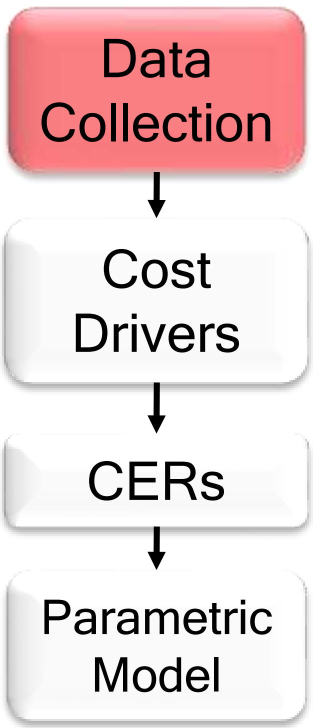
Tip: Data collection and cost driver identification are an iterative process.

Process - Data Collection



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1. 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

Tip: It is important to document sources, reasoning, assumptions, and raw data so that the development of the parametrics can be traced.

Process – Cost Drivers

Data Collection
↓
Cost Drivers
↓
CERs
↓
Parametric Model

2. 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

2

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Warning: Parameters that drive design are *not* always the parameters that drive cost.

Cost Drivers → Cost

Cost Drivers vs. Cost Passengers

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Data Collection → **Cost Drivers** → CERs → Parametric Model

- Cost drivers are characteristics that drive cost
  - Parameters with greatest leverage on cost – WHY and HOW
  - Identifying usually requires understanding, expertise
  - 16 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

Process - CERs

Data Collection → Cost Drivers → **CERs** → Parametric Model

3. 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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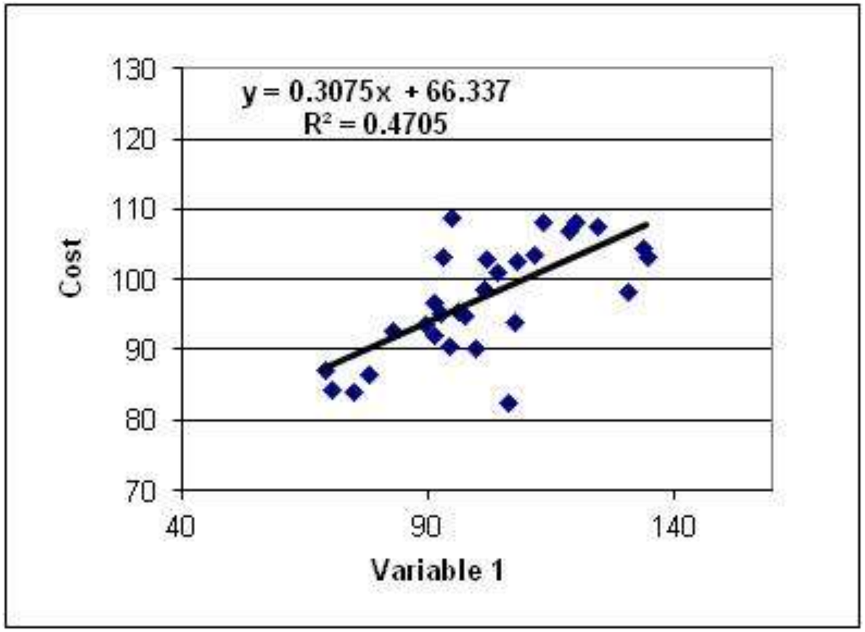

CERs - Rates, Factors, and Ratios

Data Collection → Cost Drivers → **CERs** → Parametric Model

- Rates: Cost on Parameter **4**
  - 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) **5**
- Ratios: Parameter on Parameter **6**
  - Example: 1,200 lines of code to integrate a COTS software package (industry average)

Warning: These three terms are sometimes carelessly used interchangeably.

CERs - Regression

- The preferred method for deriving CERs is via regression analysis:
  1. Select Variables
  2. Test Relationships
  3. Perform Regression
     - Examples of equations:
       - Linear: $y=a+bx$
       - Power: $y=ax^b$
       - Logarithmic: $y=a+b \ln x$
       - Exponential: $y=ae^{bx}$
       - Polynomial: $y=a+b_1x+b_2x^2+b_3x^3+\ldots+b_nx^n$

Data Collection → Cost Drivers → **CERs** → Parametric Model

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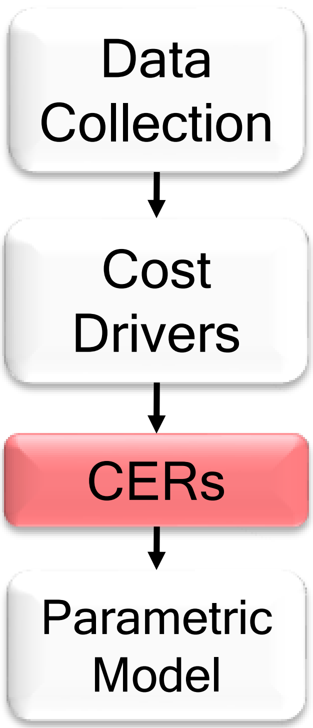
CERs – Regression



- The preferred method for deriving CERs is via regression analysis:

4. Select CERs
5. Validate CERs
   - Graphical & Ordinary Least Squares (OLS)
   - Calibration Set vs. Prediction Set
   - Repeat from step 1 as necessary

Tip: The derived CER can readily be applied to values both within and outside the range of the data used to derive the relationship. Use the Prediction Interval methodology to accurately capture uncertainty.

8 9 8

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

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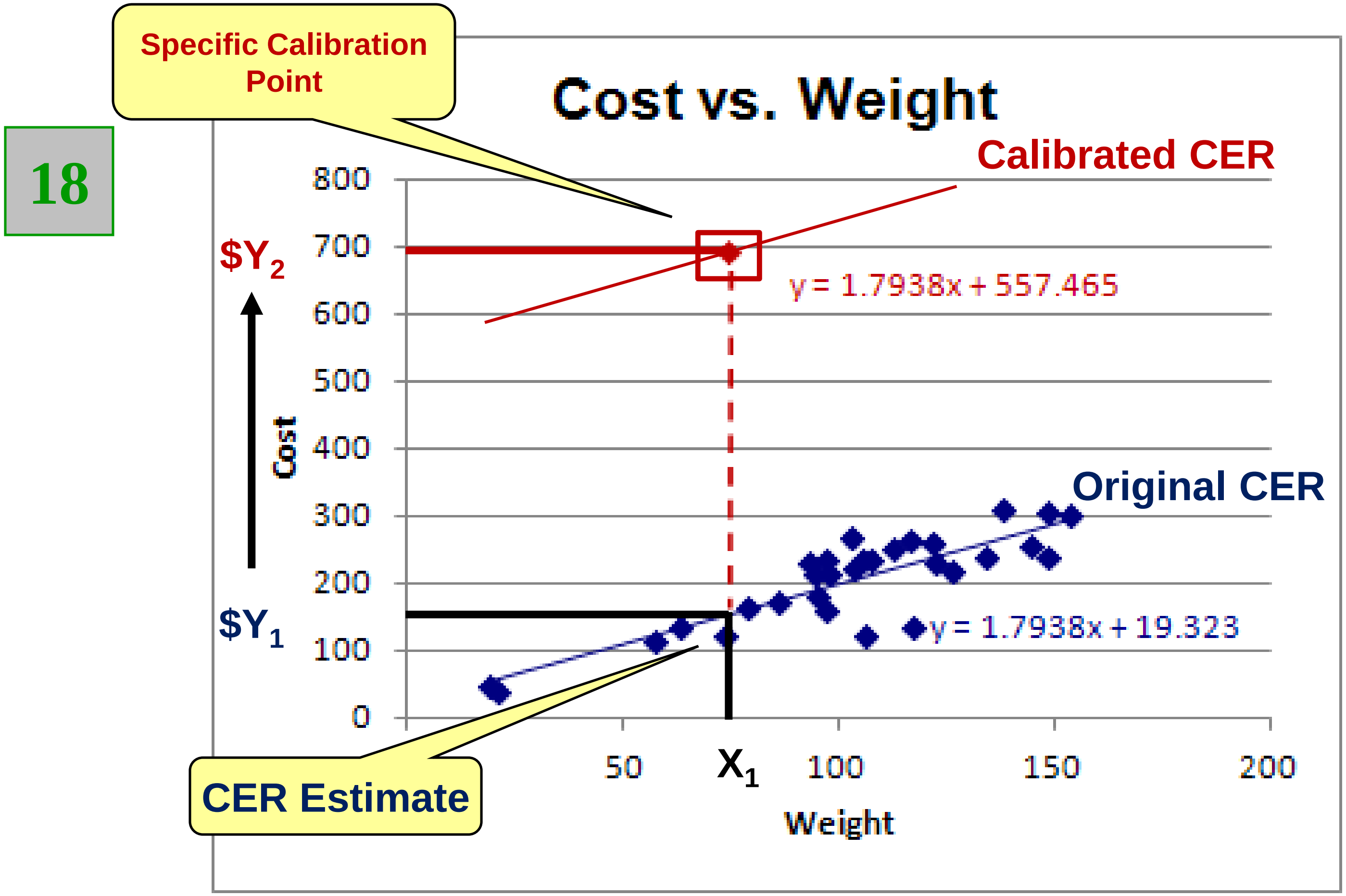
Warning: Never calibrate to a single point in the data set on which the CER is based!

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

Example - Calibrating Parametric CERs



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

Process - Parametric Model

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Data Collection
↓
Cost Drivers
↓
CERs
↓
Parametric Model

4. 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!

9

- 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)

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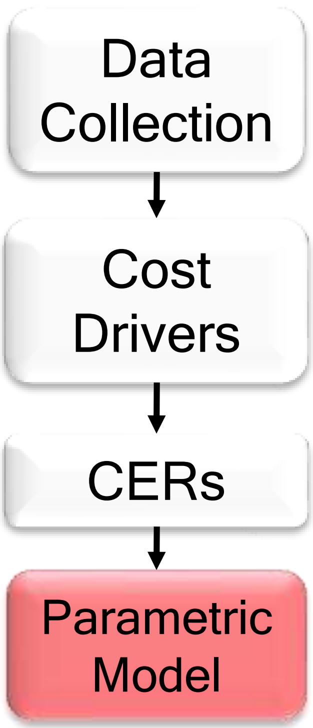
Complex Parametric Models



- Consist of more than a single CER
- May contain a number of different estimating techniques
  - CERs, discrete estimates, etc.
- 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.

Parametric Estimating Handbook (4th ed.), ISPA, 2008.

Parametric Process Examples

Example - Data Collection

- Example: Site Activation as a function of the number of workstations
- Hypothesis: There exists a cost relationship for Site Activation to be calculated as a function of the quantity of workstations per site.

Data Collection → Cost Drivers → CERs → Parametric Model

Independent Variable

Dependent Variable

	X Cost Driver Number of Workstations	Y Cost in BY ($K)
Site 1	8	$ 398
Site 2	28	$ 769
Site 3	12	$ 430
Site 4	9	$ 199
Site 5	21	$ 447
Site 6	29	$ 851
Site 7	47	$ 1,258
Site 8	7	$ 359
Site 9	36	$ 1,267
Site 10	9	$ 300
Site 11	7	$ 275

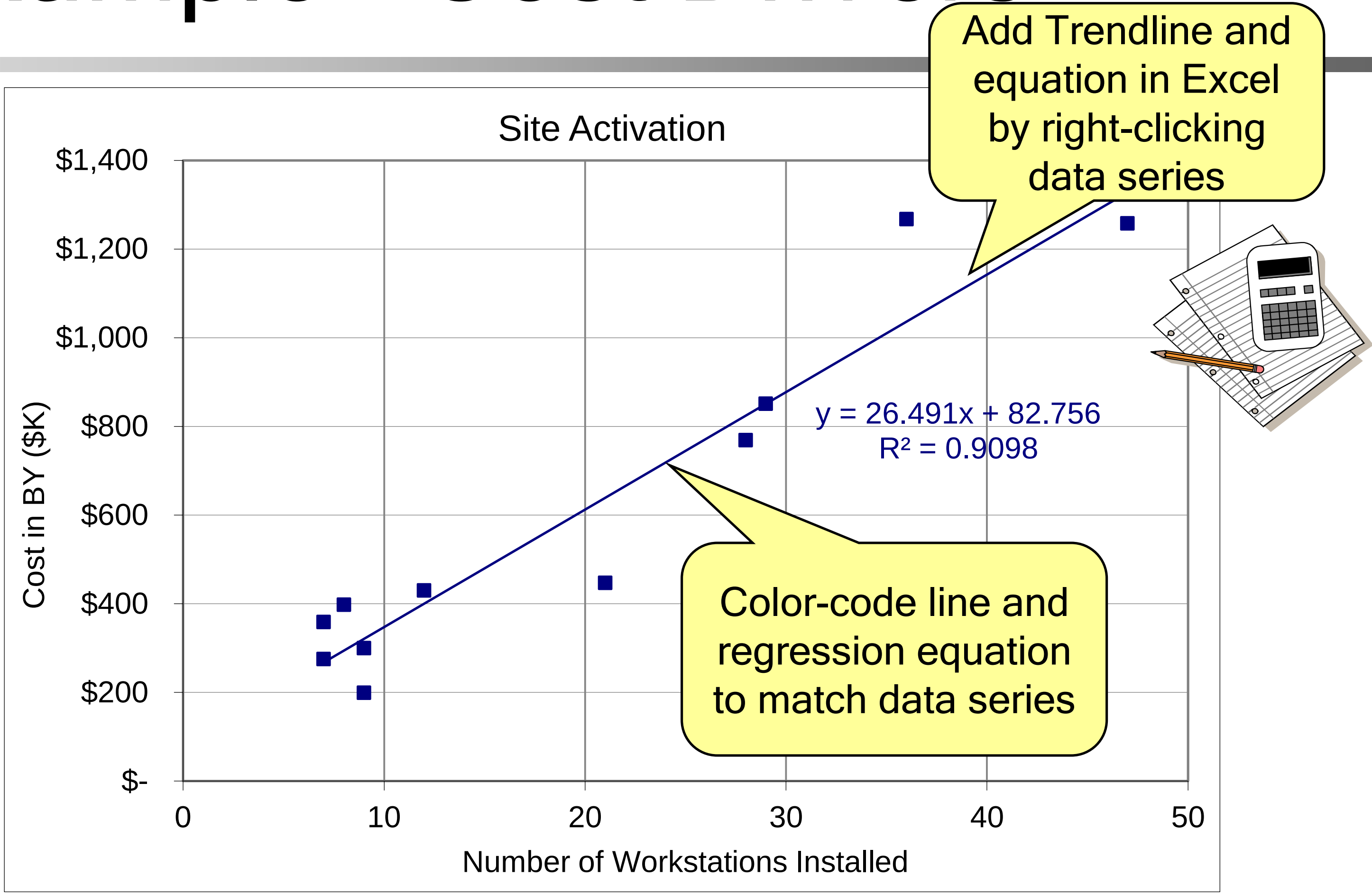
Example - Cost Drivers

Data Collection

Cost Drivers

CERs

Parametric Model



Tip: Always be sure to scatter plot your data first. Scatter plots can help identify cost drivers.

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Example - CERs

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- Site Activation Example:

Data Collection → Cost Drivers → **CERs** → Parametric Model

$$y = 26.491x + 82.756$$

$$R^2 = 0.9098$$

Equation Parameters

Ratio of explained variation to total variation in the data set

CV = std error/mean
= 121.66/595.73 = 20.4%

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.953833897
R Square	0.909799102
Adjusted R Square	0.89977678
Standard Error	121.6606251
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1343622.413	1343622.413	90.77727729	5.34455E-06
Residual	9	133211.7692	14801.30769		
Total	10	1476834.182			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	82.75641026	65.14834309	1.270276516	0.235841095	-64.61949303	230.1323135	-64.61949303	230.1323135
X Variable 1	26.49145299	2.780463527	9.52771102	5.34455E-06	20.20160271	32.78130327	20.20160271	32.78130327

8 10

Inspect the t and F statistics for significance
If p-value < significance level (α=0.05), then coefficient is significant

9

Example – Updated CER

- Updating and re-running the CER Example for Site Activation

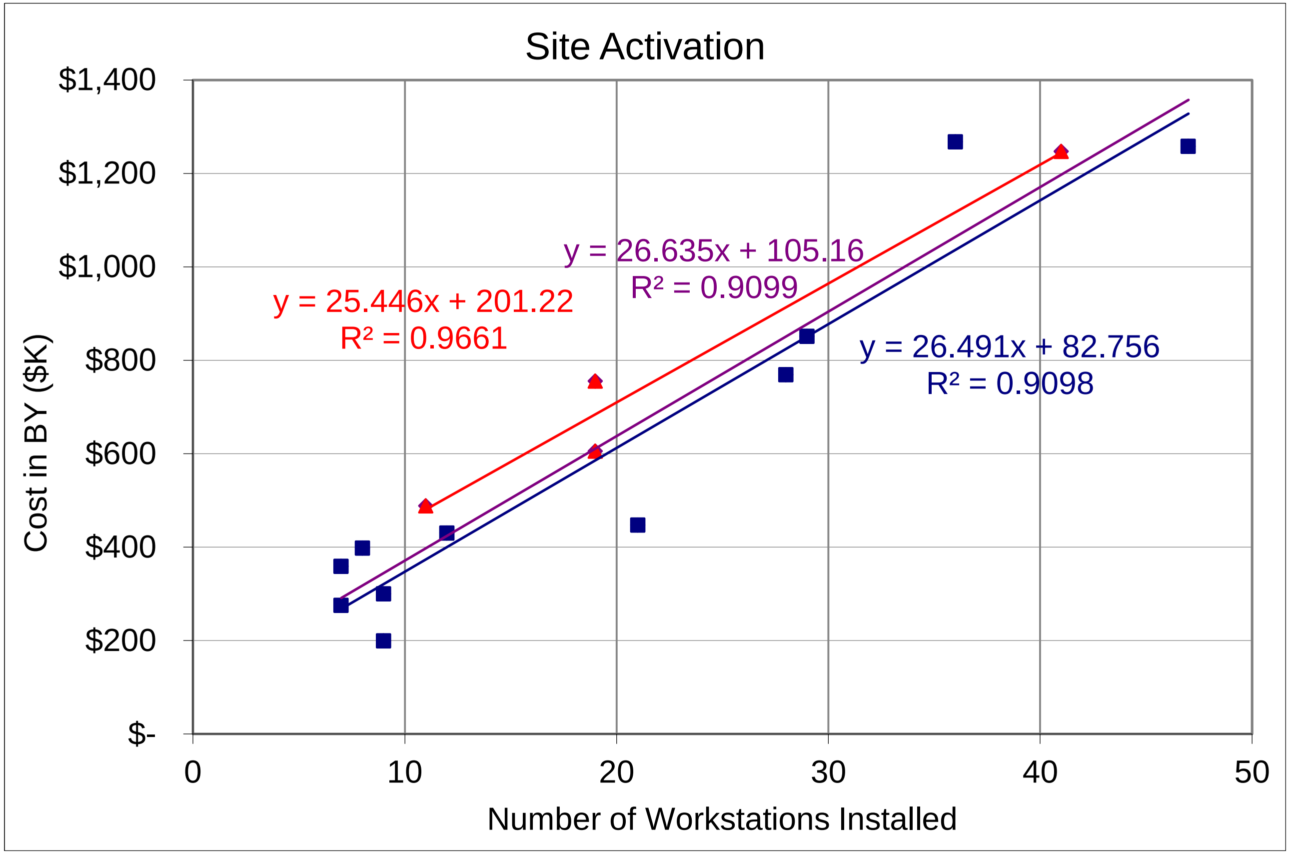
Data Collection → Cost Drivers → CERs → Parametric Model

Adding Sites 12 - 15:

	X Cost Driver Number of Workstations	Y Cost in BY ($K)
Site 1	8	$ 398
Site 2	28	$ 769
Site 3	12	$ 430
Site 4	9	$ 199
Site 5	21	$ 447
Site 6	29	$ 851
Site 7	47	$ 1,258
Site 8	7	$ 359
Site 9	36	$ 1,267
Site 10	9	$ 300
Site 11	7	$ 275
Site 12	11	$ 488
Site 13	19	$ 755
Site 14	41	$ 1,247
Site 15	19	$ 605

Example – Updated CER Graph

Data Collection → Cost Drivers → CERs → Parametric Model



$y = 26.491x + 82.756$

$R^2 = 0.9098$

→

$y = 26.635x + 105.16$

$R^2 = 0.9099$

Example - Updated CER Regression

- Site Activation Example:

Data Collection → Cost Drivers → CERs → **Parametric Model**

$$y = 26.635x + 105.16$$

$$R^2 = 0.9099$$

Equation Parameters

Ratio of explained variation to total variation in the data set

CV = std error/mean
= 114.86/643.20 = 17.9%

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95
R Square	0.91
Adjusted R Square	0.90
Standard Error	114.86
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1732752.60	1732752.60	131.35	0.000000036
Residual	13	171491.80	13191.68		
Total	14	1904244.40			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	105.164101	55.527605	1.893907	0.080704	-14.795974	225.124176	-14.795974	225.124176
X Variable 1	26.635441	2.324029	11.460888	0.000000	21.614681	31.656200	21.614681	31.656200

8 10

Inspect the t and F statistics for significance
If p-value < significance level (α=0.05), then coefficient is significant

Multivariate Example

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- In some cases, multiple cost drivers (independent variables) are used to better predict cost
  - Low R^2 with single variable regressions
  - Complexity of requirement scope
  - Brief example follows

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Multivariate Example - Data Collection

- Data Collection
- Cost Drivers
- CERs
- Parametric Model

- Data collected with two independent variables:

Multivariate Example Data			
	Purchased Services in BY ($K)	Cold Iron Hours	Comple-ment
Frigate A	$ 387.56	4727	203
Destroyer B	$ 439.66	4635	306
Destroyer C	$ 582.75	5021	317
Destroyer A	$ 469.24	4796	321
Cruiser C	$ 413.00	4280	369
Cruiser A	$ 617.91	5174	413
Cruiser B	$ 705.16	4795	461

Multivariate Example - Cost Drivers

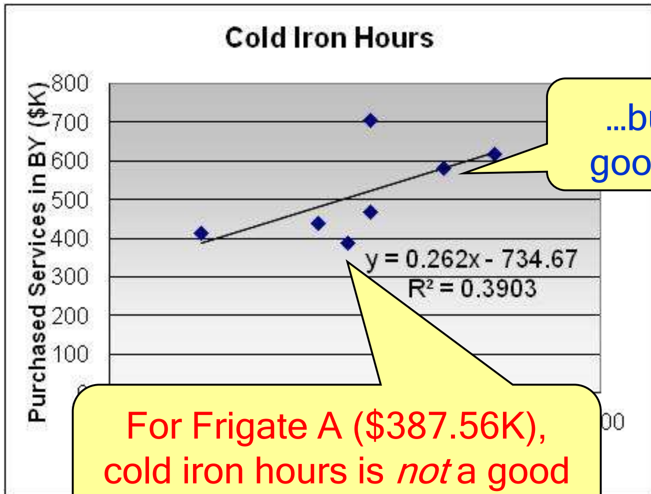
Data Collection

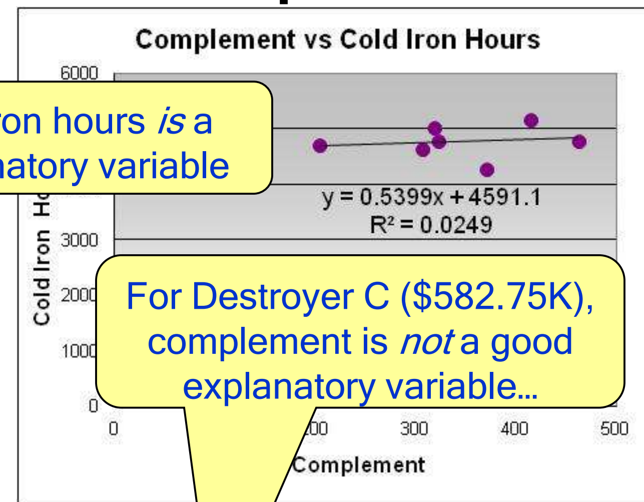
Cost Drivers

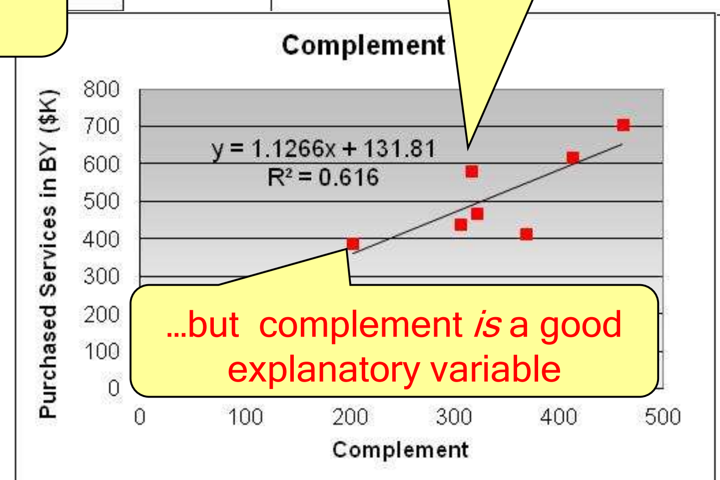
CERs

Parametric Model

- Purchased Services Example:







…but cold iron hours *is* a good explanatory variable

For Frigate A ($387.56K), cold iron hours is *not* a good explanatory variable…

For Destroyer C ($582.75K), complement is *not* a good explanatory variable…

…but complement *is* a good explanatory variable

In some areas, Cold Iron Hours and Complement by themselves are not good predictors of Purchase Services

8

Multivariate Example - CERs

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Data Collection → Cost Drivers → **CERs** → Parametric Model

- Purchased Services Example:

$$y = 0.215x_1 + 1.01x_2 - 854.3$$

$$R^2 = 0.8732$$

Equation Parameters

Tip: Intercept does *not* represent fixed cost!

Ratio of explained variation to total variation in the data set

CV = std error/mean
= 52.13/574.58 = 9.1%

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.934462283
R Square	0.873219758
Adjusted R Square	0.809829638
Standard Error	52.13001587
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	74869.97435	37434.98717	13.77532882	0.01607323
Residual	4	10870.15422	2717.538555		
Total	6	85740.12857			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-854.2676929	358.213134	-2.384802822	0.075593456	-1848.828855	140.2934695	-1848.828855	140.2934695
Cold Iron Hours	0.214824888	0.075578629	2.842402553	0.046753766	0.004984539	0.424665237	0.004984539	0.424665237
Complement	1.009958432	0.258711303	3.903804826	0.017485119	0.291659214	1.728257649	0.291659214	1.728257649

8 10

Inspect the t and F statistics for significance:
If p-value < significance level (α=0.05),
then coefficient is significant

Pairwise Scatter Plots

- In the previous question, three scatter plots were required in order to see the relationship of each of two parameters with cost, and (pairwise) with each other
- What is the general formula (in simplest form) for the number of scatter plots required to do this, given k parameters?
  - k scatter plots of parameters with cost
  - C(k,2) scatter plots of parameters with each other
  - $k+C(k,2) = k + k(k-1)/2 = (k^2+2k-k)/2 =$

k(k+1)/2 scatter plots in total

Parametric Estimating Summary

- Parametric Estimating uses cost estimating relationships (CERs) based on historical data to predict cost
- Until actual cost data are available, the use of parametric costing techniques is the preferred approach
- Parametric estimating process
  - Collecting Data
  - Identifying Cost Drivers
  - Developing CERs
  - Building a parametric model
- OTS Cost Models are convenient to use but must be applied with caution

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Resources – Guidance

- DoD 5000.4-M, Department of Defense Manual Cost Analysis Guidance and Procedures, December 1992
  - http://www.dtic.mil/whs/directives/corres/pdf/500004m.pdf
- International Society of Parametric Analysts (ISPA), Parametric Estimating Handbook, 4th Edition, April 2008
  - http://www.iceaaonline.com/ready/wp-content/uploads/2014/03/2008-Parametric-Estimating-Handbook-4th-Edition.pdf
- GAO-09-3SP, GAO Cost Estimating and Assessments Guide, Best Practices for Developing and Managing Capital Program Costs, March 2009
  - http://www.gao.gov/new.items/d093sp.pdf

Resources – Papers

- "Cost Response Curves - Their generation, their use in IPTs, Analyses of Alternatives, and Budgets," K.J. Allison, K.E. Crum, R.L. Coleman, R.G. Klion, DoDCAS, 1996
- "Analogies: Techniques for Adjusting Them," R. L. Coleman, J. R. Summerville, S. S. Gupta, SCEA 2004 & MORSS 2004
- "Galaxy Charts: The 1,000-Light-Year View of the Data," Robert Nehring, Katharine Mann, and Robert Jones, SCEA/ISPA, 2012

Related and Advanced Topics

- Cost Response Curves (CRCs)
- Parametric Analysis of Technical Parameters
- Inputs Risk Illustration
- Commonly Used
  Off-The-Shelf Cost Models

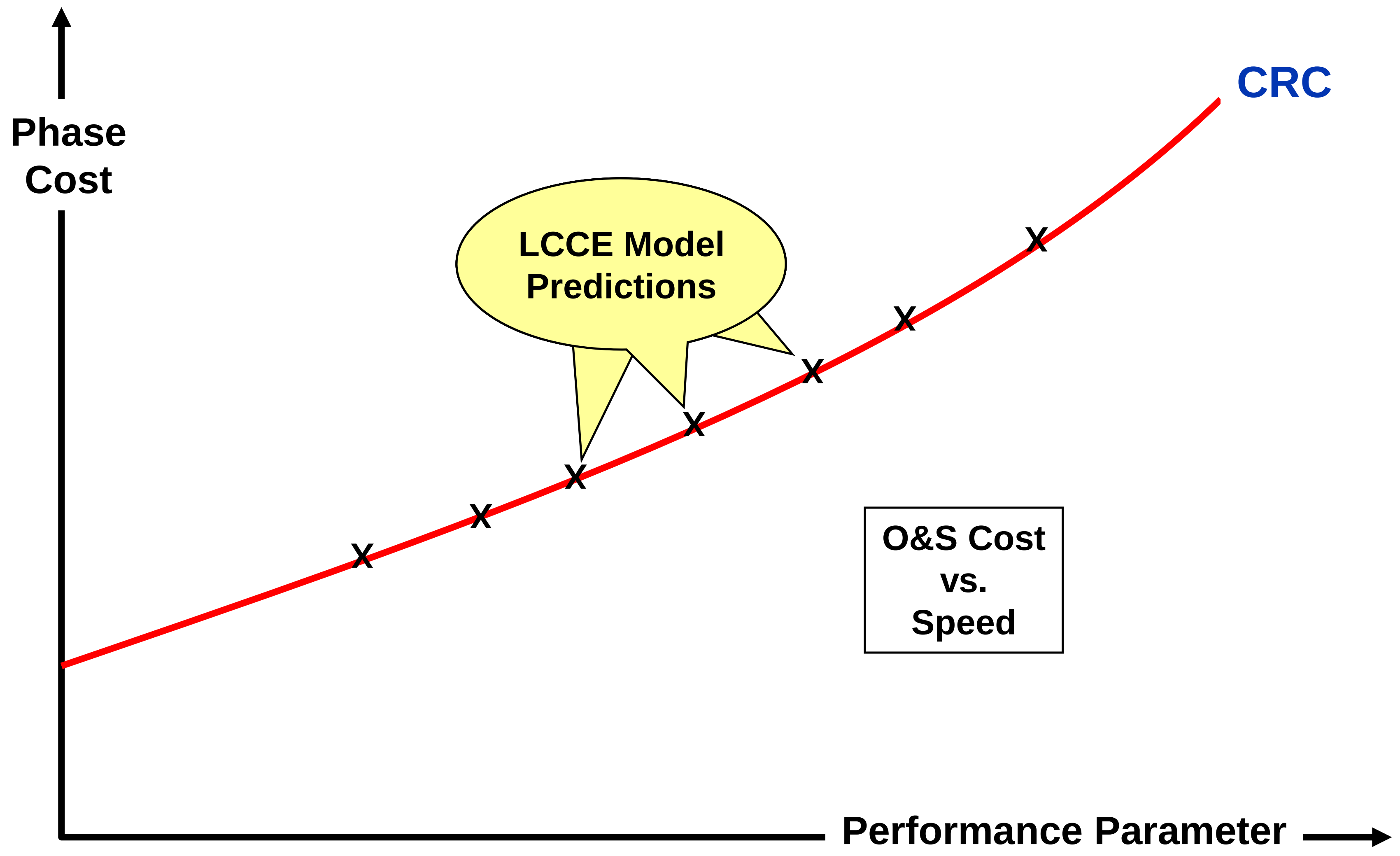
Cost Response Curves (CRCs)

- Relate total or phase costs to some specific attribute or decision variable
- Developed from cost estimating models
  - Yield costs that the cost model would, but are portable and easy to use
  - Must very nearly replicate cost model output to be usable
- Portray, one variable at a time, the effect of changing variables
  - Allow decision makers and non-cost analysts to experiment with operational parameters, with costs that remain faithful to the underlying cost model

CRCs don't make you smarter – They make you equally dumb faster!

"Cost Response Curves - Their generation, their use in IPTs, Analyses of Alternatives, and Budgets," K.J. Allison, K.E. Crum, R.L. Coleman, R.G. Klion, DoDCAS, 1996

CRC Example


CRC
Phase Cost
LCCE Model Predictions
X
X
X
X
X
X
X
X
O&S Cost vs. Speed
Performance Parameter

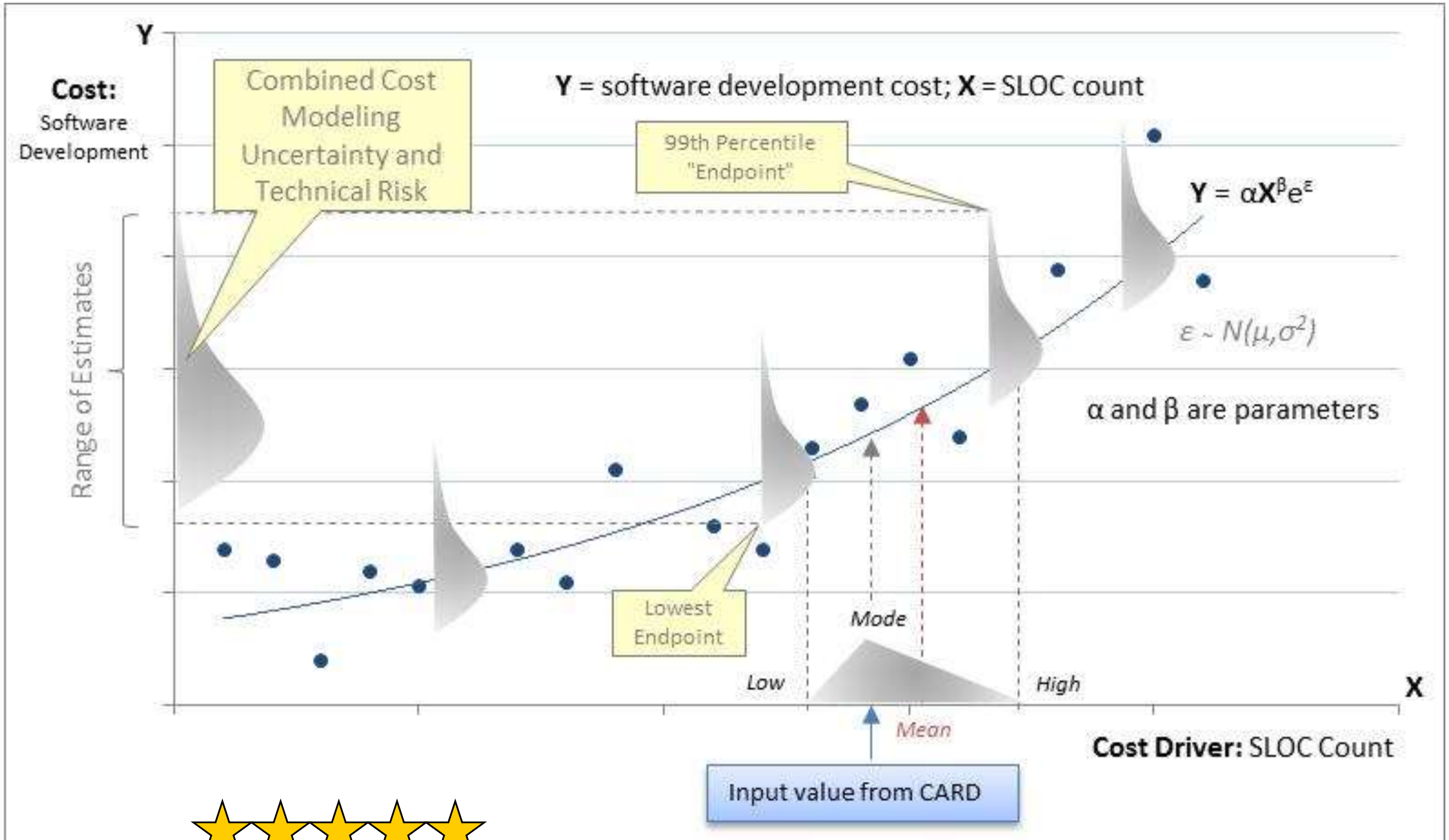
Parametric Analysis of Technical Parameters

- The parametric estimating process can also be used to estimate technical parameters
- Estimating Process:
  - Collect data from historical programs
  - Identify drivers
    - Identify parameters whose values appear to drive the technical parameter that you are trying to estimate
  - Develop estimating relationship
    - The dependent variable is a technical parameter (e.g., weight) instead of cost
  - Build a parametric model

“New Challenges for Cost Analysts: Creating Technical Baselines for Point Estimates,” S.B. Toas, J. Frisbie, D. Thomas, SCEA/ISPA, 2008.

“Incremental Weight and Cost Model,”, B.A. Brophy, R.L. Coleman, J.R. Summerville, P.J. Braxton, SCEA/ISPA, 2005.

Inputs – Risk



Department of the Navy Independent Cost Analysis Manual, Naval Center for Cost Analysis (NCCA), March, 2013.

Off-The-Shelf Cost Models

- Off-The-Shelf Cost Models cover a range of estimation domains (hardware, software, electronics, IT) and will estimate most phases of a system life cycle
  - Estimates from OTS cost models can be used for some or all of an overall system estimate
  - Knowledge based cost models can be used out of the box or can be tuned and calibrated to an organization’s data/experience
  - OTS cost models can be used to enforce estimation best practices and estimate process maturity

OTS Cost Models – PRICE

- **PRICE Systems, L.L.C., Mt. Laurel, NJ with offices worldwide**
  - Founded in 1975
  - Assisting government and industry globally to manage costs throughout program total life cycle
  - Products: **TruePlanning**® and the **PRICE ® Models**
    - **TruePlanner** ®(estimating framework), **TrueFindings** ®(analytics) and **TrueMapper** ®(WBS/CES mapping) integrated analytical cost modeling system
    - **Systems Cost Model** – estimates the cost of management, oversight, and integration costs for hardware, software, and information technology systems
    - **Hardware Cost Model** – provides cost estimates for hardware based on industry data and CERs (newest generation of PRICE H ®)
    - **Software Cost Model** - predicts costs, resources, and schedules for software projects (newest generation of PRICE S ®)
    - **IT Infrastructure Cost Model** – estimates the cost of IT infrastructure to include resource allocation and life cycle maintenance
    - **Specialized Models** – Rotorcraft, Space Mission, Fuel Cells and many more

HW Estimating	✓
SW Estimating	✓
O&S Estimating	✓
Other	✓

OTS Cost Models – SEER

- **Galorath Incorporated, El Segundo, CA**
  - Founded1979
  - Assisting government and industry to estimate, plan and control project costs, schedule and risk
  - Products: SEER solutions can be used independently or as part of an integrated suite
    - **SEER for Software (SEER-SEM™)** – estimates the cost, schedule, effort, risk & reliability of software/application development, system integration and test and maintenance
    - **SEER for Hardware, Electronics & Systems (SEER-H™)** – estimates life cycle costs for any size hardware project, from individual components to complete product assemblies and subsystems. Specialty models address FPGA, ASIC, Sensors, as well as standard modules for mechanical, structural and electronics estimation
    - **SEER for Manufacturing (SEER-MFG™)** – based upon industry time & motion based labor standards, SEER-MFG provides a bottom up estimate for a vast array of metallic, non-metallic, fabrication and assembly manufacturing processes
    - **SEER for IT (SEER-IT™)** – estimates total ownership costs of deploying and ongoing support of IT systems, including infrastructure, applications, databases and end user systems. Also estimates systems engineering effort. Estimates include cost, schedule, effort and staffing requirements.

HW Estimating	✓
SW Estimating	✓
O&S Estimating	✓
Other	✓

OTS Cost Models – COCOMO II

HW Estimating	
SW Estimating	✓
O&S Estimating	
Other	

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- Constructive Cost Model (COCOMO)
- The original COCOMO model
  - First published by Dr. Barry Boehm in 1981
  - Widely used software project cost estimation model
  - Also existed in other incarnations, the most prominent being Ada COCOMO
- COCOMO II
  - Reinvented in the 1990s
  - Revised cost estimation model reflecting the changes in professional software development practice that have come about since the 1970s

COCOMO *and* its CERs are publicly available

OTS Cost Models – ACEIT

Tip: ACEIT is a tool / framework, not an "out-of-the-box" model

HW Estimating	
SW Estimating	
O&S Estimating	
Other	✓

- Automated Cost Estimating Integrated Tools (ACEIT), Tecolote Research, Inc., 1973
  - Tool developed to standardize the Life Cycle Cost estimating process in the government environment
  - Full CER library for government users
- ACEIT integrated tools:
  - Automated Cost Database development, search, and retrieval (ACDB)
  - Statistical analysis/methodology development (CO$TAT)
  - Methodology library creation (Librarian)
  - Cost estimate development and documentation (ACE)
  - Automated integration with other applications (ACE Plug-Ins)
  - Risk Analyis (RI$K)
  - Charting and tabular reports (POST)
  - Capability for customization and integration (ACE API)

Resources – OTS Models

- TruePlanning and the PRICE Models (PRICE Systems)
  - http://www.pricesystems.com/
- SEER (Galorath)
  - http://www.galorath.com/index.php/products
- COCOMO (USC CSE)
  - http://csse.usc.edu/csse/research/COCOMOII/cocomo_main.html
- ACEIT (Tecolote)
  - https://www.aceit.com/home