COCOMO:

ANSWERING THE MOST FREQUENT QUESTIONS

BARRY BOEHM

TRW

MAY 1985
OUTLINE

- RECENT COCOMO CALIBRATION, VALIDATION
- SIZING
- SMALL MODS TO LARGE PROGRAMS
- LOOSELY-COUPLED PRODUCTS
- NEW TECHNOLOGY EFFECTS
  - ADA, VHLL'S, Prototyping
- LIFE-CYCLE COST ESTIMATION
RECENT CALIBRATION AND VALIDATION:

EFFORT ESTIMATION

- Organization A -- Good Fit
- Organization B -- Very Good Fit
- ICL -- Poor Fit
- Student Projects -- Needed Recalibration
- Fujitsu -- Needed Recalibration
COCOMO ESTIMATES VS. ACTUALS: ORGANIZATION A

ACTUALS (MM)

COCOMO ESTIMATES (MM)

EST = ACT
20% OFF

O - ORGANIC
X - SEMIDETACHED
\(\cdot\) - EMBEDDED

18 PROJECTS
14 WITHIN 20%
Figure 9.2 Relationship Between Actuals and Estimates for Intermediate COCOMO

- **BT Developments**
- **ICL Developments**

Projects 15, 19 & 20 not plotted
Projects 12-14, 17-18 not available
COCOMO ESTIMATES VS ACTUALS; 7 STUDENT PROJECTS

ACT = .51 (EST)
FIGURE 6. INTERMEDIATE COCOMO ESTIMATES VS. ACTUALS
FIGURE 9. TAILORED COCOMO ESTIMATES VS. ACTUALS
(B & C CALIBRATION)

\[ NEM = 3.19(KDSI)^{0.89} \]
SUMMARY: COCOMO EFFORT ESTIMATION

- Some organizations fit existing model well
- Some organizations fit once assumptions are reconciled
  - Phase endpoints, rating scales, effort counted
- Some organizations don't fit any model well
- Most organizations fit reasonably well
  (within 20%, 70% of time), once calibrated
COST DRIVER RATING SCALES

• EFFECTIVE TO ILLUSTRATE RATING LEVELS USING FAMILIAR LOCAL PROJECTS

• BEHAVIORAL RATING SCALES
  - 70% STORAGE CONSTRAINT

• MIXED SITUATIONS
  - HOST-TARGET: TIME, STOR, VIRT, TURN
  - RESTRICTED INTERACTIVE ACCESS

• COMPLEXITY RELATIVE TO PERSONNEL

• NEW RATING LEVELS & MULTIPLIERS
  - TURN, TOOL
EFFECT OF 70% STORAGE CONSTRAINT

1. BRUTE-FORCE APPROACH, EVENTUALLY FILLS 70%
   - NO PENALTY

2. REQUIRED SOFTWARE FILLS 70%.
   - STANDARD "70%" EFFECT

3. MORE REQUIRED SOFTWARE,
   REQUIREMENT TO USE ONLY 70% OF STORAGE
   - PRELIM, DESIGN
     DETAILED DESIGN
     CODE & UNIT TEST
   - INTEGRATION & TEST - "85%" EFFECT

EFFORT MULTIPLIERS:

<table>
<thead>
<tr>
<th>RPD</th>
<th>DD</th>
<th>CUT</th>
<th>IT</th>
<th>OVERALL</th>
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<tr>
<td>1.55</td>
<td>1.45</td>
<td>1.45</td>
<td>1.35</td>
<td>1.43</td>
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**Host - Target Effects**

**Virtual Machine Volatility**

- Preliminary Design
- Detailed Design
- Code & Unit Test

**Host; Low Volatility**

**Integration & Test**

**Target; High Volatility**

---

**Effort Multipliers**

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<thead>
<tr>
<th>RPD</th>
<th>DD</th>
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<th>Overall</th>
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<td>.95</td>
<td>.90</td>
<td>.85</td>
<td>1.20</td>
<td>.98</td>
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NEW RATING LEVELS AND MULTIPLIERS: TRW SOFTWARE PRODUCTIVITY SYSTEM EXPERIENCE

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>MAN-MONTHS</th>
<th>ESTIMATED</th>
<th>ACTUAL</th>
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<td></td>
<td>STD. COCOMO</td>
<td>NEW RATINGS</td>
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<td>1</td>
<td>46.4</td>
<td>39.0</td>
<td>40</td>
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<td>2</td>
<td>74.8</td>
<td>62.8</td>
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**RATINGS**

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<th>TURN: LOW</th>
<th>RPD</th>
<th>DD</th>
<th>CUT</th>
<th>IT</th>
<th>OVERALL</th>
<th>PROD/Y RANGE</th>
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<td>VERY LOW</td>
<td>.98</td>
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<td>.87</td>
<td>1.32</td>
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<td>TOOL: VERY HIGH</td>
<td>.85</td>
<td>.85</td>
<td>.65</td>
<td>.85</td>
<td>.79</td>
<td>1.46</td>
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<tr>
<td>EXTRA HIGH</td>
<td>.95</td>
<td>.90</td>
<td>.70</td>
<td>.70</td>
<td>.83</td>
<td>1.49</td>
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<td></td>
<td>.90</td>
<td>.85</td>
<td>.75</td>
<td>.67</td>
<td>.77</td>
<td>1.61</td>
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SOFTWARE COST ESTIMATION
ACCURACY VS. PHASE

-7 PROGRAMS WITH SAME REQUIREMENTS

EXAMPLE SOURCES OF UNCERTAINTY:
MAN-MACHINE INTERFACE SOFTWARE

Classes of People, Data Sources to Support
Query types, Data loads, Smart-terminal tradeoffs, Response times

Internal Data Structure, Buffer handling techniques

Detailed Scheduling Algorithms, Error handling

Programmer understanding of Spec

Size Relative Cost Range

Size Cost Range

Feasibility Plans and ROTS Product Design Spec. Detail Design Spec. Accepted Software


Phases and Milestones

Phases and Milestones

2-22
WHAT DOES A SOFTWARE PRODUCT DO?

SUMMARY OF TWO PRODUCTS DEVELOPED TO SAME BASIC SPECIFICATION
(SMALL, INTERACTIVE SOFTWARE COST MODEL)

PERCENT OF SOURCE LINES OF CODE

- PROJECT 1
- PROJECT 2

MODEL CALC USER INPUTS USER OUTPUTS CONTROL HELP MSG PROC ERROR PROC MOVING DATA AROUND DATA DECL, FORMATS COMMENTS
EFFECT OF OBJECTIVES ON PRODUCTIVITY
(WEINBERG-SCHULMAN, 1974)

<table>
<thead>
<tr>
<th>TEAM OBJECTIVE: OPTIMIZE</th>
<th>NUMBER OF STATEMENTS</th>
<th>MAN-HOURS</th>
<th>PRODUCTIVITY (STATE/M-H)</th>
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<tbody>
<tr>
<td>CORE MEMORY</td>
<td>52</td>
<td>74</td>
<td>0.7</td>
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<tr>
<td>NUMBER OF STATEMENTS</td>
<td>33</td>
<td>30</td>
<td>1.1</td>
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<tr>
<td>EXECUTION TIME</td>
<td>100</td>
<td>50</td>
<td>2.0</td>
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<tr>
<td>PROGRAM CLARITY</td>
<td>90</td>
<td>40</td>
<td>2.2</td>
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<td>PROGRAMMING MAN-HOURS</td>
<td>126</td>
<td>28</td>
<td>4.5</td>
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<tr>
<td>OUTPUT CLARITY</td>
<td>166</td>
<td>30</td>
<td>5.5</td>
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SOFTWARE SIZING: CONCLUSIONS

- There is no royal road to software sizing
  - No substitute for understanding the job
  - PERT standard deviations can be misleading

- Need to understand sources of underestimation
  - Housekeeping software
  - Support software
  - Project overhead functions
  - Personnel overhead functions
  - Desire to please

Establish corporate memory
  - Software cost office

- Use size ranges (vs. point estimates)
SMALL MODIFICATIONS TO LARGE PROGRAMS:

3 METHODS

1. ADAPTED SOFTWARE
2. "ANNUAL CHANGE TRAFFIC"
3. DIFFERENTIAL DEVELOPMENT

EXAMPLE

ADAPTED SOFTWARE = 100 KDSI

DESIGN MODIFIED = 10%
CODE MODIFIED = 20%
INTEGRATION REQUIRED = 5%

ADDED SOFTWARE = 2 KDSI

- Assume nominal effort multipliers
APPROACH 1: ADAPTED SOFTWARE

\[ \text{AAF} = 0.4(1) + 0.3(2) + 0.3(5) = 2.5 \]

\[ \text{EDSI} = (100 \times \text{KDSI}) \times 0.025) = 2.5 \times \text{KDSI} \]

\[ \text{TOTAL EDSI} = 2.5 + 2 = 4.5 \times \text{KDSI} \]

If organic mode, \[ \text{MM} = 3.2 \times (4.5)^{1.05} = 15.5 \text{ MM} \]

If embedded mode, \[ \text{MM} = 2.8 \times (4.5)^{1.20} = 17.0 \text{ MM} \]
Approach 2: "Annual Change Traffic"

Code Modified = 100 KDSI (0.02) = 2 KDSI
Code Added = 2 KDSI

ACT = \frac{2 + 2}{100} = 0.04

If Organic Mode, \[ MM = (0.04) 3.2 (100)^{1.05} = 16.1 \text{ MM} \]
If Embedded Mode, \[ MM = (0.04) 2.8 (100)^{1.20} = 28.1 \text{ MM} \]
**Approach 3: Differential Development**

If Organic Mode, \[ MM = 3.2 (102)^{1.05} - 3.2 (100)^{1.05} \]
\[ = 411.3 - 402.8 \]
\[ = 8.5 \text{ MM} \]

If Embedded Mode, \[ MM = 2.8 (102)^{1.20} - 2.8 (100)^{1.20} \]
\[ = 720.2 - 703.3 \]
\[ = 16.9 \text{ MM} \]
## SUMMARY OF APPROACHES

<table>
<thead>
<tr>
<th>Method</th>
<th>If Organic</th>
<th>If Embedded</th>
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<tbody>
<tr>
<td>1. Adapted Software</td>
<td>15.5</td>
<td>17.0</td>
</tr>
<tr>
<td>2. Annual Change Traffic</td>
<td>16.1</td>
<td>28.1</td>
</tr>
<tr>
<td>3. Differential Development</td>
<td>8.5</td>
<td>16.9</td>
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</tbody>
</table>

- Choose method best fitting situation
- Or, determine appropriate average
LOOSELY-COUPLED PRODUCTS:
STRATEGIC DEFENSE INITIATIVE EXAMPLE

- SINGLE, EMBEDDED-MODE, 10 MDSI PRODUCT

\[ \text{MAN-YEARS} = 2.8 \left(10,000\right)^{1.20} \div 12 = 14,722 \text{ MY} \]

- MIX OF OPERATIONAL, SUPPORT SOFTWARE
- EMBEDDED: 2,000 KDSI - \( \text{MY} = 2.8 \left(2000\right)^{1.20} \div 12 = 2134 \text{ MY} \)
- SEMI-DET: 4,000 KDSI - \( \text{MY} = 3.0 \left(4000\right)^{1.12} \div 12 = 2705 \)
- ORGANIC: 4,000 KDSI - \( \text{MY} = 3.2 \left(4000\right)^{1.05} \div 12 = 1615 \frac{6454 \text{ MY}}{} \)

INTEGRATION FACTOR:
\( \left(10,000\right)^{1.05} \div 10,000 = 1.585 \)

INTEGRATION ADJUSTMENT:
\( \text{MY} = \left(6454\right) \left(1.585\right) = 10,229 \text{ MY} \)
NEW TECHNOLOGY EFFECTS

- ADA
- VERY HIGH LEVEL LANGUAGES
- PROTOTYPING
**ADA Effects: IDA Study**

*DOUVILLE ET AL., 1985*

- Use COCOMO ratings to estimate impact of ADA vs. COBOL on MMCCS
- 13-person Delphi study

<table>
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<tr>
<th>Change Due to ADA</th>
<th>Near-Term</th>
<th>Long-Term</th>
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<tr>
<td>Development Effort/KDSI</td>
<td>+30</td>
<td>-40</td>
</tr>
<tr>
<td>Maintenance Effort/KDSI</td>
<td></td>
<td>-75</td>
</tr>
<tr>
<td>KDSI</td>
<td>(-5, -10)</td>
<td>-50</td>
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EFFECTS OF VHLL'S ON SOFTWARE PRODUCTIVITY
-BUSINESS APPLICATIONS, UCLA, 1982

<table>
<thead>
<tr>
<th>EXPERTISE</th>
<th>COMPLEXITY</th>
<th>DEVELOPMENT MAN-HOURS</th>
<th>SOURCE INSTRUCTIONS</th>
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<td>FOCUS</td>
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<td>BEGINNER</td>
<td>SIMPLE</td>
<td>31.25</td>
<td>14</td>
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<tr>
<td></td>
<td></td>
<td>55.50</td>
<td>11</td>
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<tr>
<td>BEGINNER</td>
<td>COMPLEX</td>
<td>95</td>
<td>11.75</td>
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<td>SIMPLE</td>
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<td>4.32</td>
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<td>COMPLEX</td>
<td>16</td>
<td>8.75</td>
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<tr>
<td></td>
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<td>74</td>
<td>49</td>
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**EvoluTionary Prototyping**

- 3 projects developing COCOMO models

<table>
<thead>
<tr>
<th>Project</th>
<th>DSI</th>
<th>Man-Hours</th>
<th>Prod'y Increase</th>
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<tr>
<td></td>
<td>Proto.</td>
<td>Total</td>
<td>Proto.</td>
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<tr>
<td>2A</td>
<td>1000</td>
<td>1952</td>
<td>102</td>
</tr>
<tr>
<td>2B</td>
<td>1200</td>
<td>2726</td>
<td>129</td>
</tr>
<tr>
<td>2C</td>
<td>800</td>
<td>1514</td>
<td>84</td>
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</table>

*Indicated productivity increase on evolutionary prototype = 1.5*
COCOMO LC MODEL DESCRIPTION

- Similar to COCOMO Development Model

- Different size parameter
  - Annual change traffic

- Cost driver ratings for annual maintenance

- Some different effort multipliers
  - Required reliability
  - Use of modern programming practices

- Development schedule factor dropped
EXAMPLE: AVIONICS LIFE CYCLE COST

- DEVELOPMENT COST ESTIMATE

- MAINTENANCE COST ESTIMATE
  - 10 YEAR PERIOD
  - EW P³I EFFORT IN YEAR 3
  - YEARS 5-10 ALIKE

- USAGE CROSS CHECKS
<table>
<thead>
<tr>
<th>FACTOR</th>
<th>RATING</th>
<th>MULT.</th>
<th>FACTOR</th>
<th>RATING</th>
<th>MULT.</th>
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<tr>
<td>RELY</td>
<td>HI</td>
<td>1.15</td>
<td>AEXP</td>
<td>HI</td>
<td>.91</td>
</tr>
<tr>
<td>DATA</td>
<td>NOM</td>
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<td>PCAP</td>
<td>NOM</td>
<td>1.0</td>
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<tr>
<td>CPLX</td>
<td>HI</td>
<td>1.15</td>
<td>NEXP</td>
<td>HI</td>
<td>.90</td>
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<td>TIME</td>
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<td>LEXP</td>
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<td>NOM</td>
<td>1.0</td>
<td>MODP</td>
<td>HI</td>
<td>.91</td>
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<tr>
<td>VIRT</td>
<td>HI</td>
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<td>TOOL</td>
<td>NOM</td>
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<td>HI</td>
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<td>NOM</td>
<td>1.0</td>
<td></td>
<td></td>
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</table>

|TT| = |1.18|

SIZE: 40 KDSI

MODE: EMBEDDED

\[ MM_{\text{nom}} = 2.8 \times (40)^{1/2} = 234 \text{ mm} \]

\[ MM_{\text{dev}} = (234) \times (1.18) = 276 \text{ mm} \]
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5-10</th>
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<td>40</td>
<td>44</td>
<td>50</td>
<td>60</td>
<td>66</td>
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<tr>
<td><strong>MM</strong></td>
<td>234</td>
<td>262</td>
<td>306</td>
<td>381</td>
<td>427</td>
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<tr>
<td><strong>% ADD</strong></td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>10</td>
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<td><strong>% MOD</strong></td>
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<td><strong>STOR</strong></td>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<td><strong>VIRT</strong></td>
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<td>1.0</td>
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<td>0.91</td>
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<td>0.95</td>
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<td><strong>MODP</strong></td>
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<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
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<td><strong>SCED</strong></td>
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<td>45</td>
<td>55</td>
<td>91</td>
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<td>42</td>
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<td><strong>FSP</strong></td>
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<td>4.6</td>
<td>7.6</td>
<td>5.8</td>
<td>3.5</td>
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<tr>
<td><strong>KDS5/FSP</strong></td>
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<td>9.6</td>
<td>6.6</td>
<td>10.3</td>
<td>18.7</td>
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ESTIMATED LIFE-CYCLE STAFFING PROFILE

MAINTENANCE YEAR

STAFF LEVEL (FSP)

LEVEL 1 2 3 4 5 6 7 8 9 10
Usage Cross Checks

\[
\frac{\text{Maint MM}}{\text{Life-Cycle MM}} = \frac{513}{513 + 276} = 65\%.
\]

Typical = 67\%.

\[
\text{KDSI/FSR} = 6.6 - 18.7
\]

Typical = 8 - 10
ANNUAL CHANGE TRAFFIC BY APPLICATIONS AREA

ANNUAL CHANGE TRAFFIC (ACT)
SUMMARY

- COCOMO IS A BEGINNING, NOT AN END
- IT DOESN'T HAVE ALL THE ANSWERS
- BUT WITH GOOD ENGINEERING JUDGEMENT,
  YOU CAN EXTEND IT TO PROVIDE MORE ANSWERS
- PRESENTATIONS TO COME ARE EXAMPLES OF THIS
1985 and Since

**1985: Several Active Cost Estimation Models**
- PRICE S (Freiman-Park)
- SLIM (Putnam)
- JS-1, 2 (Jensen)
- SPQR (Jones)
- Estimacs (Rubin)
- Softcost-R (Reifer)
- COCOMO: WICOMO (Ligett), GECOMO (Rook), PCOC (Royce), GHL COCOMO (Lazarev), others

**1985 ICSE 8 Model Estimate Comparison (Rubin)**
- 60 KSLOC project description
  - 112.5 PM – Estimacs
  - 200 PM -- SLIM
  - 363 PM -- GECOMO
  - 940 PM -- JS-2
Since 1985: Impact of Cost Estimation Research

• Impact on Rest of Software Engineering
  – Process Engineering
  – Product Engineering
  – Property Modeling
  – Personnel Management

• Impact on Software Engineering Practice
Impact on Software Process Engineering

- Anchor Point milestones for spiral development
  - Developed as COCOMO II effort estimation endpoints
  - Adopted by Rational Unified Process

- Quantitative project phase and activity guidelines
  - Basis for planning and control

- Quantitative basis for timeboxing
  - Schedule or cost as independent variable

- Processes for COTS-based system development
  - Process happens where the effort happens
  - COTS assessment, tailoring, integration
Impact on Software Product Engineering

• COTS implications for requirements, architecture
  – It’s not a requirement if you can’t afford it

• How much architecting is enough?
  – Function of size, criticality, volatility

• Product-line development
  – Costs of developing for reuse, with reuse
  – Increased payoffs in total ownership cost
Impact on Software Property Modeling

• Economics of software quality
  – Quality is free? – under what conditions?
    • High cost of defects; long lifetime
• Starting point for value-based software engineering
  – Comparative costs and benefits of features
• Quantitative basis for risk analysis
  – Monte Carlo assessment of cost driver uncertainties
  – Cone of uncertainty in cost estimation accuracy
• Calibrated cost effects of quality attributes
  • Desired reliability, performance, schedule
Impact on Personnel Management

• Magnitude of personnel effects on software costs
  – Calibrated factor-of-16 potential range of productivity
  – Including capability, experience, turnover effects

• Cheaper personnel cause costlier projects
  – Salary ranges narrower than productivity ranges

• Importance of good management
  – Addressed in Jensen and Jones models
Impact on Software Engineering Practice

- Avoiding unrealistic commitments
  - Over 25% schedule compression “impossible zone”
- Objective basis for contract negotiation
- Business case assessment for proposed projects
- Quantitative basis for project planning and control
- Quantitative basis for make-or-buy decisions
- Quantitative basis for maintain-replace decisions
- Quantitative basis for productivity improvement decisions
- Quantitative basis for risk-based “how much is enough?” decisions

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Estimation Challenges for the Future

- Mixed COTS, cloud, and custom systems
- Net-centric systems of systems
- Ultra-reliable systems
- Multicore chips and parallel programming
- Brownfield systems
- Model-driven development
- Incremental and evolutionary development
  - Incremental development productivity decline
  - Dual cones of uncertainty
Rapid Change Creates a Late Cone of Uncertainty
– Need evolutionary/incremental vs. one-shot development

Uncertainties in competition, technology, organizations, mission priorities

Relative Cost Range

Feasibility
Concept of Operation
Rqts. Spec.
Product Design Spec.
Detail Design Spec.
Devel. and Test

Accepted Software

Phases and Milestones