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
COCOM O ESTIMATES VS. ACTUALS: ORGANIZATION A

ACTUALS (MM)

COCOMO ESTIMATES (MM)

18 PROJECTS
14 WITHIN 20%

o - ORGANIC
x - SEMIDETACHED
Δ - EMBEDDED

EST = ACT

20% OFF
Figure 9.2 Relationship Between Actuals and Estimates for Intermediate COCOMO

- ○ BT Developments
- X ICL Developments

Projects 15, 19 & 20 not plotted
Projects 12-14, 17-18 not available
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
   -- "95%" EFFECT
   -- 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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</table>
HOST - TARGET EFFECTS:
VIRTUAL MACHINE VOLATILITY

- PRELIM. DESIGN
  DETAILED DESIGN
  CODE & UNIT TEST

- INTEGRATION & TEST -

HOST; LOW VOLATILITY
TARGET; HIGH VOLATILITY

EFFORT MULTIPLIERS

<table>
<thead>
<tr>
<th>RPD</th>
<th>DD</th>
<th>CUT</th>
<th>IT</th>
<th>OVERALL</th>
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</thead>
<tbody>
<tr>
<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: TRN Software Productivity System Experience

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

<table>
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<th>RPD</th>
<th>DD</th>
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<th>IT</th>
<th>OVERALL</th>
<th>PRODL RANGE</th>
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<tr>
<td>Turn: Low</td>
<td>.98</td>
<td>.95</td>
<td>.70</td>
<td>.90</td>
<td>.87</td>
<td>1.32</td>
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<td>Turn: Very Low</td>
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<td>.85</td>
<td>.65</td>
<td>.85</td>
<td>.79</td>
<td>1.46</td>
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<td>Tool: Very High</td>
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<td>.90</td>
<td>.90</td>
<td>.70</td>
<td>.83</td>
<td>1.49</td>
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<tr>
<td>Tool: Extra High</td>
<td>.90</td>
<td>.85</td>
<td>.75</td>
<td>.67</td>
<td>.77</td>
<td>1.61</td>
</tr>
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</table>
SOFTWARE COST ESTIMATION

ACCURACY VS. PHASE

-7 PROGRAMS WITH SAME REQUIREMENTS
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

<table>
<thead>
<tr>
<th>Category</th>
<th>Project 1</th>
<th>Project 2</th>
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<tr>
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<tr>
<td>User Inputs</td>
<td></td>
<td></td>
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<tr>
<td>User Outputs</td>
<td></td>
<td></td>
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<tr>
<td>Control</td>
<td></td>
<td></td>
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<tr>
<td>Help MSG Proc</td>
<td></td>
<td></td>
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<tr>
<td>Error Proc</td>
<td></td>
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<tr>
<td>Moving Data Around</td>
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<td></td>
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<tr>
<td>Data Decl, Formats</td>
<td></td>
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<tr>
<td>Comments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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>
</tr>
<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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<tr>
<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 = 1%
CODE MODIFIED = 2%
INTEGRATION REQUIRED = 5%

ADDED SOFTWARE = 2 KDSI

ASSUME NOMINAL EFFORT MULTIPLIERS...
**Approach 1: Adapted Software**

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

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

**Total EDSI** = \(2.5 + 2 = 4.5 \text{ KDSI}\)

**If Organic Mode**, \(\text{MM} = 3.2 \left(4.5\right)^{1.05} = 15.5 \text{ MM}\)

**If Embedded Mode**, \(\text{MM} = 2.8 \left(4.5\right)^{1.20} = 17.0 \text{ MM}\)
APPROACH 2: "ANNUAL CHANGE TRAFFIC"

\[
\text{CODE MODIFIED } = 100 \text{ KDSI (1.02)} = 2 \text{ KDSI}
\]

\[
\text{CODE ADDED } = 2 \text{ KDSI}
\]

\[
\text{ACT } = \frac{2 + 2}{100} = .04
\]

\[
\text{IF ORGANIC MODE, } \text{MM} = (.04) 3.2 (100)^{1.05} = 16.1 \text{ MM}
\]

\[
\text{IF EMBEDDED MODE, } \text{MM} = (.04) 2.8 (100)^{1.20} = 28.1 \text{ MM}
\]
**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></th>
<th>IF ORGANIC</th>
<th>IF EMBEDDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ADAPTED SOFTWARE</td>
<td>15.5</td>
<td>17.0</td>
</tr>
<tr>
<td>2. ANNUAL CHANGE</td>
<td>16.1</td>
<td>28.1</td>
</tr>
<tr>
<td>TRAFFIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. DIFFERENTIAL</td>
<td>8.5</td>
<td>16.9</td>
</tr>
<tr>
<td>DEVELOPMENT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- SINGLE, EMBEDDED-MODE, 10 MDSI PRODUCT

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

- MIX OF OPERATIONAL, SUPPORT SOFTWARE

- EMBEDDED: 2000 KODSI - \( \text{MY} = 2.8 \times (2000)^{1.20} / 12 = 2134 \text{ MY} \)
- SEMI-DET: 4000 KODSI - \( \text{MY} = 3.0 \times (4000)^{1.05} / 12 = 2705 \)
- ORGANIC: 4000 KODSI - \( \text{MY} = 3.2 \times (4000)^{1.05} / 12 = 1615 \)

\[
\text{INTEGRATION FACTOR:} \\
(10,000)^{1.05} / 10,000 = 1.585
\]

\[
\text{INTEGRATION ADJUSTMENT:} \\
\text{MY} = (6454) (1.585) = 10,229 \text{ MY}
\]
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 WWMCCS

- 13-person Delphi study

<table>
<thead>
<tr>
<th>Change due to ADA</th>
<th>Near-term</th>
<th>Long-term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development effort/KDDI</td>
<td>+30</td>
<td>-40</td>
</tr>
<tr>
<td>Maintenance effort/KDDI</td>
<td></td>
<td>-75</td>
</tr>
<tr>
<td>KDDI</td>
<td>(-5, -10)</td>
<td>-50</td>
</tr>
</tbody>
</table>
### 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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cobol</td>
<td>Focus</td>
</tr>
<tr>
<td>Beginner</td>
<td>Simple</td>
<td>31.25</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55.50</td>
<td>11</td>
</tr>
<tr>
<td>Beginner</td>
<td>Complex</td>
<td>95</td>
<td>11.75</td>
</tr>
<tr>
<td>Expert</td>
<td>Simple</td>
<td>26</td>
<td>4.32</td>
</tr>
<tr>
<td>Expert</td>
<td>Complex</td>
<td>16</td>
<td>8.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>74</td>
<td>49</td>
</tr>
</tbody>
</table>
## Evolutionary Prototyping

- **3 Projects Developing COCOMO Models**

<table>
<thead>
<tr>
<th>Project</th>
<th>DSI</th>
<th>Man-Hours</th>
<th>Prody Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proto</td>
<td>Total</td>
<td>%</td>
</tr>
<tr>
<td>2A</td>
<td>1000</td>
<td>1952</td>
<td>.51</td>
</tr>
<tr>
<td>2B</td>
<td>1200</td>
<td>2726</td>
<td>.44</td>
</tr>
<tr>
<td>2C</td>
<td>800</td>
<td>1514</td>
<td>.53</td>
</tr>
</tbody>
</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>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>RELY</td>
<td>HI</td>
<td>1.15</td>
<td>AEXP</td>
<td>HI</td>
<td>0.91</td>
</tr>
<tr>
<td>DATA</td>
<td>NOM</td>
<td>1.0</td>
<td>PCAP</td>
<td>NOM</td>
<td>1.0</td>
</tr>
<tr>
<td>CPLX</td>
<td>HI</td>
<td>1.15</td>
<td>VEXP</td>
<td>HI</td>
<td>0.90</td>
</tr>
<tr>
<td>TIME</td>
<td>NOM</td>
<td>1.0</td>
<td>LEXP</td>
<td>NOM</td>
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</tr>
<tr>
<td>STOR</td>
<td>NOM</td>
<td>1.0</td>
<td>MODP</td>
<td>HI</td>
<td>0.91</td>
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<tr>
<td>VIRT</td>
<td>HI</td>
<td>1.15</td>
<td>TOOL</td>
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<td>TURN</td>
<td>NOM</td>
<td>1.0</td>
<td>SCEO</td>
<td>HI</td>
<td>1.04</td>
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<tr>
<td>ACAP</td>
<td>NOM</td>
<td>1.0</td>
<td></td>
<td></td>
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</tbody>
</table>

\[ \text{TT} = 1.18 \]

**SIZE**: 40 KDSI  
**Mode**: EMBEDDED  

\[ \text{MM}_{\text{Nom}} = 2.8 \times 40^{1/2} = 234 \text{ mm} \]

\[ \text{MM}_{\text{Dev}} = (234) \times 1.18 \times 1.18 = 276 \text{ mm} \]
## Avionics Maintenance Cost Estimate

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5-10</th>
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<tbody>
<tr>
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<td>44</td>
<td>50</td>
<td>60</td>
<td>66</td>
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<td>MM</td>
<td>2.34</td>
<td>262</td>
<td>306</td>
<td>381</td>
<td>427</td>
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<tr>
<td>% MOD</td>
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<td>20</td>
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<tr>
<td>% MOD</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>15</td>
<td>15</td>
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<tr>
<td>ACT</td>
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<td>2.5</td>
<td>4.0</td>
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### Raw Data:

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<th>Component</th>
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<td>1.15</td>
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<td>1.0</td>
<td>1.06</td>
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<td>VIRT</td>
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<td>1</td>
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<td>1</td>
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<td>.91</td>
<td>.91</td>
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<td>Nom</td>
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<td>1</td>
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<td>.90</td>
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<td>MOVG</td>
<td>HI</td>
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<td>1.86</td>
<td>1.86</td>
<td>1.86</td>
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### Total:

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<tr>
<th>Component</th>
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<th>276</th>
<th>55</th>
<th>91</th>
<th>70</th>
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<td>MM AM</td>
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<td>4.5</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
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<tr>
<td>FSP AM</td>
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<td>4.6</td>
<td>7.6</td>
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<tr>
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<td>10.6</td>
<td>9.6</td>
<td>6.6</td>
<td>10.3</td>
<td>18.7</td>
</tr>
</tbody>
</table>

**Total:** 573
ESTIMATED LIFE-CYCLE STAFFING PROFILE

STAFF LEVEL (FSP)

MAINTENANCE YEAR

LEVEL 1 2 3 4 5 6 7 8 9 10
\[
\frac{\text{MAINT MM}}{\text{LIFE-CYCLE MM}} = \frac{513}{513 + 276} = 65\%.
\]

Typical = 67\%

\[
\frac{\text{KDSI/FSP}}{\text{Typical}} = 6.6 - 18.7
\]

Typical = 8 - 10
CARD-PEK-PERSON RATIO BY APPLICATION TYPE

\[ \frac{KDSI}{FSP} \]

Bus.  Control  User  S/F  SCS  System  Support
ANNUAL CHANGE TRAFFIC BY APPLICATIONS AREA

ANNUAL CHANGE TRAFFIC (ACT)

BUS. CONTROL USER I/F SCI SYSTEM SUPPORT
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