# SOFTWARE EFFORT AND SCHEDULE ESTIMATION USING THE CONSTRUCTIVE COST MODEL: COCOMO II

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## Introduction

During development of a software product, several questions arise:
- How long will it take to develop?
- How much will it cost?
- How many people will be needed?

In answering these questions, several others arise:
- What are the risks involved if we compress the schedule by a certain fraction?
- Can we invest more in strategies such as tools, reuse, and process maturity and get higher productivity, quality and shorter cycle times?
- How can the cost and schedule be broken down by component, stage and activity?

COCOMO II facilitates the planning process by enabling one to answer the above questions using a parametric model that has been calibrated to actual completed software projects collected from Commercial, Aerospace, Government and non-profit organizations. Although, COCOMO II consists of three submodels, Applications Composition, Early Design, and Post-architecture, each one offering increased fidelity the further along one is in the project planning and design process; only the Early Design and Post Architecture models have been calibrated and implemented in the software. Due to lack of data, the Application Composition model has not yet been calibrated beyond an initial calibration to the [Kauffman93] data and hence has not yet been implemented in the USC COCOMO software. For further details on the COCOMO II model and its calibration, the reader is urged to read [Boehm95, USC-CSE97] and [Chulani98] respectively and http://sunset.usc.edu/COCOMOII/suite.html.

The next few subsections discuss the inputs and outputs of the Post Architecture implementation on USC COCOMO II.1998.0 (1998 denotes that the tool is based on the latest 1998 Bayesian calibration [Chulani98] of the model and 0 denotes the version number).

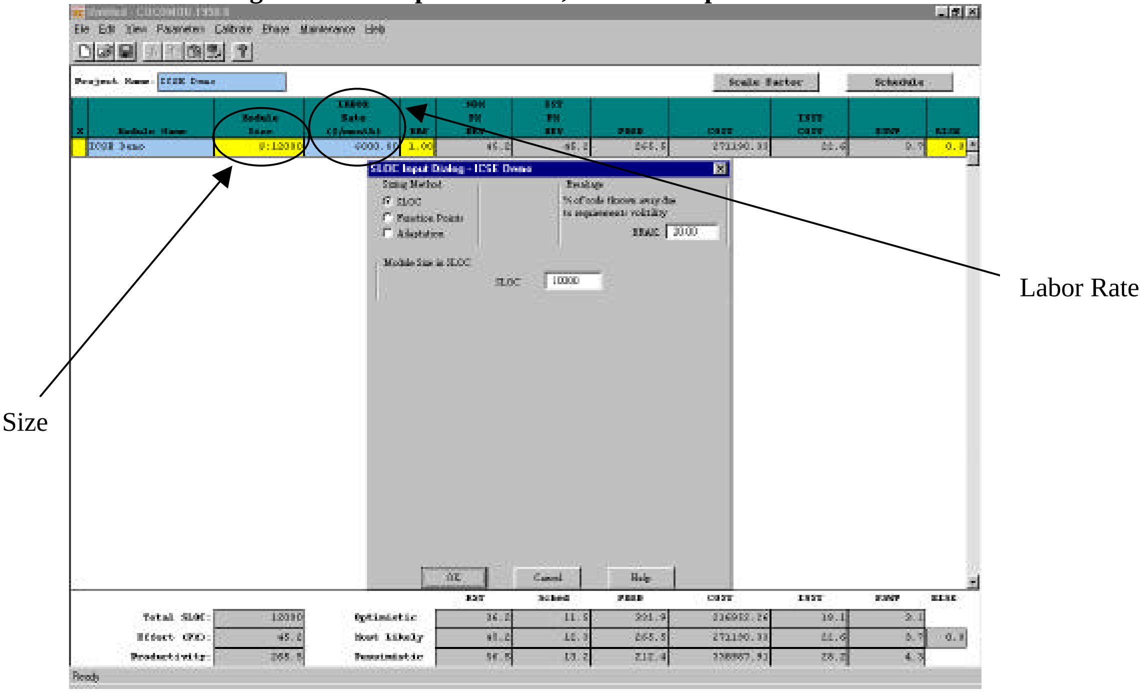
## COCOMO II Post- Architecture Model Inputs:

COCOMO II does component-level or project-level estimation of a software products and expects as input:

1. Size: in terms of SLOC (Source Lines of Code), FPs (Function Points) or Adapted SLOC as illustrated in figure 1. Lets say for our example, the Size is 10,000 SLOC and about 20% of code was thrown away due to requirements volatility, i.e. an equivalent of 2,000 instructions was discarded resulting in the BRAK value of 20. This is used to adjust the project's effective size to 12,000 instructions as shown in the Module Size field of the main estimation window.

2. Labor Rate: in terms of $/month. This is also illustrated in figure 1 where the labor rate has been input as $6,000/month.

**Figure 1: Size Input in SLOC, FPs or Adapted SLOC**


Untitled - COCOMO II.1998.0
File Edit View Parameters Calibrate Phase Maintenance Help
Scale Factor
Schedule
SLOC Input Dialog - ICSE Demo
OK
Cancel
Help
Ready
Labor Rate
Size

Project Name: ICSE Demo

| X | Module Name | Module Size | LABOR Rate ($/month) | EAF | NOM PM DEV | EST PM DEV | PROD | COST | INST COST | STAFF | RISK |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | ICSE Demo | S:12000 | 6000.00 | 1.00 | 45.2 | 45.2 | 265.5 | 271190.33 | 22.6 | 3.7 | 0.8 |

Sizing Method
◉ SLOC
○ Function Points
□ Adaptation

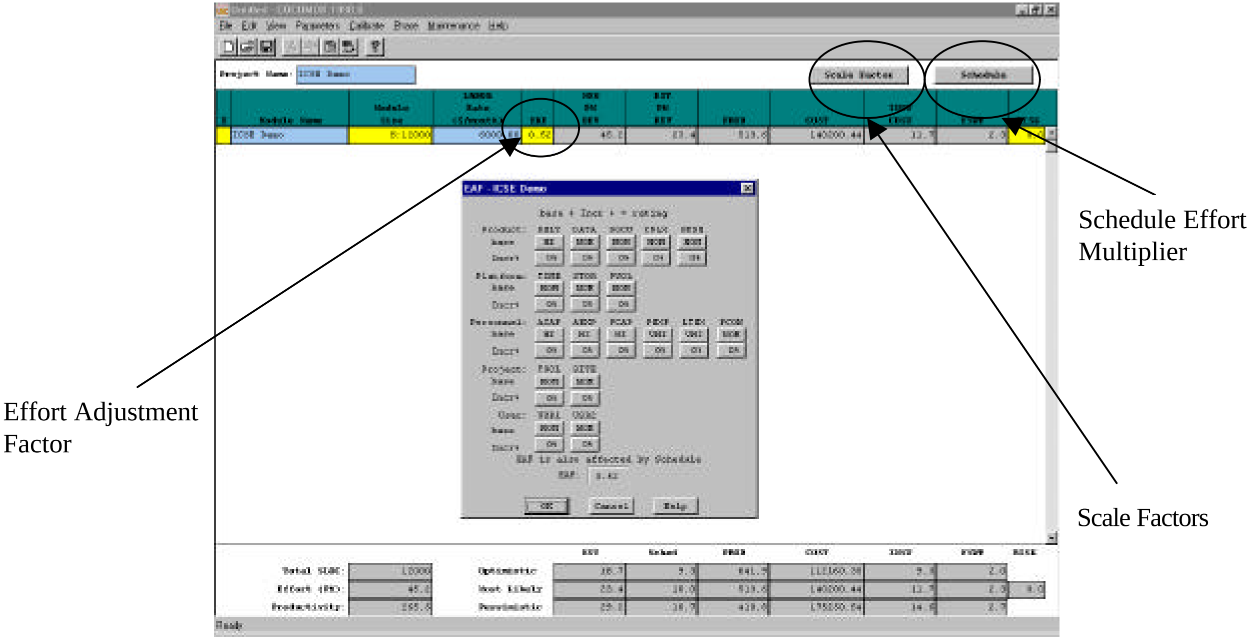
Breakage
% of code thrown away due to requirements volatility
BRAK: 20.00

Module Size in SLOC
SLOC: 10000

|  |  |  | EST | Sched | PROD | COST | INST | STAFF | RISK |
|---|---|---|---|---|---|---|---|---|---|
| Total SLOC: | 12000 | Optimistic | 36.2 | 11.5 | 331.9 | 216952.26 | 18.1 | 3.1 |  |
| Effort (PM): | 45.2 | Most Likely | 45.2 | 12.3 | 265.5 | 271190.33 | 22.6 | 3.7 | 0.8 |
| Productivity: | 265.5 | Pessimistic | 56.5 | 13.2 | 212.4 | 338987.91 | 28.2 | 4.3 |  |

3. <u>Five (5) Scale Factors (SF), Seventeen (17) Effort Multipliers (EM)</u>: These 22 input parameters differentiate two software products under development with the same size but with different process, product, platform, personnel and scaling characteristics. Figure 2 provides a snapshot of the EAF (Effort Adjustment Factor, which is the product of the effort multipliers) Input dialog box where 16 of the 17 predefined COCOMO II effort multipliers can be input. The effort multipliers have alphanumeric ratings such as Very Low, Low, Nominal, High, Very High and the calibrated model values (see the Appendix) are used to convert these rating to numeric ratings. Two user-defined effort multipliers, USR1 and USR2, allow the user to define a local variable not covered in COCOMO II (for example, Security needs). Each of the effort multipliers can have intermediate ratings that can be adjusted by the Incr% field.

**Figure 2: EAF Input Dialog Box**


Untitled - COCOMO II.1998.0
File Edit View Parameters Calibrate Phase Maintenance Help
Scale Factor
Schedule
EAF - ICSE Demo
OK
Cancel
Help
Ready
Schedule Effort Multiplier
Effort Adjustment Factor
Scale Factors

Project Name: ICSE Demo

| X | Module Name | Module Size | LABOR Rate ($/month) | EAF | NOM PM DEV | EST PM DEV | PROD | COST | INST COST | STAFF | RISK |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | ICSE Demo | S:12000 | 6000.00 | 0.52 | 45.2 | 23.4 | 513.6 | 140200.44 | 11.7 | 2.3 | 0.0 |

base + Incr % = rating

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Product: | RELY | DATA | DOCU | CPLX | RUSE |  |
| base | HI | NOM | NOM | NOM | NOM |  |
| Incr% | 0% | 0% | 0% | 0% | 0% |  |
| Platform: | TIME | STOR | PVOL |  |  |  |
| base | NOM | NOM | NOM |  |  |  |
| Incr% | 0% | 0% | 0% |  |  |  |
| Personnel: | ACAP | AEXP | PCAP | PEXP | LTEX | PCON |
| base | HI | HI | HI | VHI | VHI | NOM |
| Incr% | 0% | 0% | 0% | 0% | 0% | 0% |
| Project: | TOOL | SITE |  |  |  |  |
| base | NOM | NOM |  |  |  |  |
| Incr% | 0% | 0% |  |  |  |  |
| User: | USR1 | USR2 |  |  |  |  |
| base | NOM | NOM |  |  |  |  |
| Incr% | 0% | 0% |  |  |  |  |

EAF is also affected by Schedule
EAF: 0.52

|  |  |  | EST | Sched | PROD | COST | INST | STAFF | RISK |
|---|---|---|---|---|---|---|---|---|---|
| Total SLOC: | 12000 | Optimistic | 18.7 | 9.3 | 641.5 | 112160.38 | 9.3 | 2.0 |  |
| Effort (PM): | 45.2 | Most Likely | 23.4 | 10.0 | 513.6 | 140200.44 | 11.7 | 2.3 | 0.0 |
| Productivity: | 265.5 | Pessimistic | 29.2 | 10.7 | 410.8 | 175250.54 | 14.6 | 2.7 |  |

Schedule is the 17th effort multiplier that is a project-level (not a component-level) input and is a field on the top right corner of the main input screen. The five scale factors can also be input as alphanumeric ratings similar to the effort multipliers.

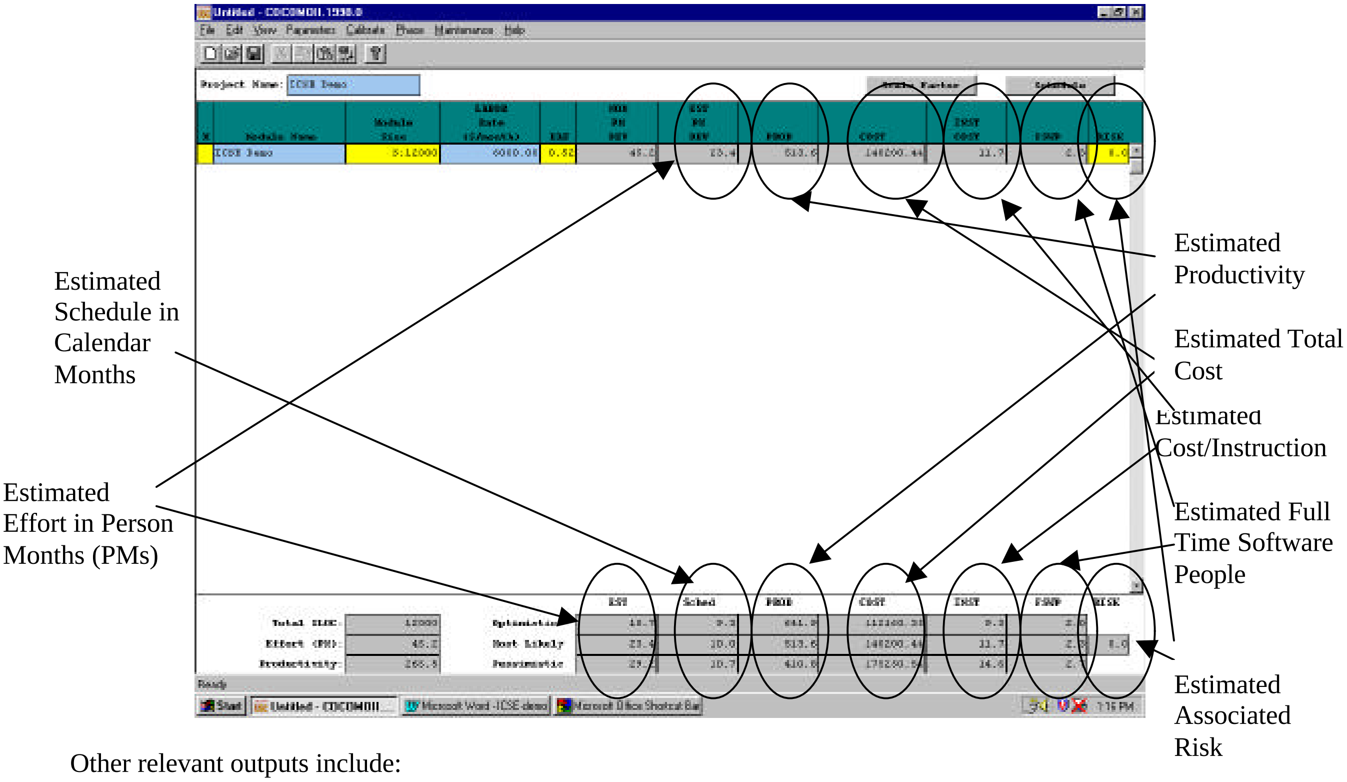
Based on these inputs, COCOMO II computes the effort, cost and schedule in addition to some other useful estimates as discussed in the following section. The equations for effort, schedule, and cost are:

$$Effort = A\prod(EM)(Size)^{B+\sum(SF)}$$
$$Schedule = C(Effort)^{D+0.2(B+\sum(SF))}$$
$$Cost = Effort(\$/month)$$

## COCOMO II Post- Architecture Model Outputs:

The primary but not the only important outputs of COCOMO II are the overall effort and schedule estimates in Person Months and Calendar Months respectively. USC COCOMO II.1998.0 not only provides point estimates but also gives a range in terms of optimistic, most likely and pessimistic estimates as illustrated in figure 3.

**Figure 3: Outputs provided by USC COCOMO II.1998.0**



Untitled - COCOMOII.1998.0
File Edit View Parameters Calibrate Phase Maintenance Help
Scale Factor
Schedule
Ready
Start
Untitled - COCOMOII...
Microsoft Word - ICSE-demo
Microsoft Office Shortcut Bar
7:15 PM
Estimated Productivity
Estimated Total Cost
Estimated Cost/Instruction
Estimated Full Time Software People
Estimated Associated Risk
Estimated Schedule in Calendar Months
Estimated Effort in Person Months (PMs)

Project Name: ICSE Demo

| X | Module Name | Module Size | LABOR Rate ($/month) | EAF | NOM PM DEV | EST PM DEV | PROD | COST | INST COST | FSWP | RISK |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | ICSE Demo | S:12000 | 6080.08 | 0.52 | 45.2 | 23.4 | 513.6 | 148200.44 | 11.7 | 2.3 | 0.0 |

|  |  |  | EST | Sched | PROD | COST | INST | FSWP | RISK |
|---|---|---|---|---|---|---|---|---|---|
| Total SLOC: | 12000 | Optimistic | 18.7 | 9.3 | 641.9 | 112160.38 | 9.3 | 2.0 |  |
| Effort (PM): | 45.2 | Most Likely | 23.4 | 10.0 | 513.6 | 148200.44 | 11.7 | 2.3 | 0.0 |
| Productivity: | 265.5 | Pessimistic | 29.2 | 10.7 | 410.8 | 175250.56 | 14.6 | 2.7 |  |

Other relevant outputs include:

- Productivity in terms of SLOC/PM (PROD)
- Total Cost of development in US Dollars (COST)
- Cost/Instruction in terms of $/SLOC (INST)
- Number of full time software people required on the project (FSWP)
- Associated Risk (RISK) which is a numeric risk rating associated with the project.

The overall effort, schedule and full time software people required can be broken down by activity.

The USC COCOMO II.1998.0 results can also be exported to a preprogrammed Excel worksheet that produces a variety of graphs and reports.

## Tailoring USC COCOMO II.1998.0 to Local Environment:

USC COCOMO II.1998.0 gives several local calibration options to the user. The user has the freedom to change any of the parameter ratings by using the "Parameters" pull down menu option and editing the appropriate rating. Even the overall effort and equation can be edited if the user wishes to use a different calibrated constant in the computations.

The "Calibrate" menu option helps the user calibrate the multiplicative and/or the exponential base constants A, B, C, and D to better suit local conditions and improve prediction accuracy. Completed projects can be stored in USC COCOMO II.1998.0 file formats and then used to locally calibrate the model.

## Conclusions:

From this informal demo, the attendee will not only learn the general concepts of software cost and schedule estimation but will also take with him a strong understanding of the underlying mathematical equations of one of the most popular and publicly available software estimation models, COCOMO II. COCOMO II helps the user for a number of purposes associated with software estimation. These include:

- Budgeting the software under development: This is the primary but not the only important use of any software estimation model. Accuracy of the overall estimate is the most desired capability and COCOMO II.1998 currently calibrated to 161 completed software projects gives effort predictions that are within 30% of the actuals 76% of the time and schedule predictions that are within 30% of the actuals 72% of the time.
- Sensitivity Analyses: This feature provided by COCOMO II helps the user in negotiations with the other stakeholders involved in the software development.
- Tradeoff and risk analysis: This is an important additional capability and USC COCOMO II.1998.0 computes a risk factor associated with the project to be estimated. For example, if the Required Reliability and Complexity of the project are Very High and the Personnel Experience and Capability factors are Very Low, then USC COCOMO II.1998.0 flags a very high risk factor of 16.
- Project planning and control: This is an important capability whereby the cost and schedule breakdowns by component, stage and activity are provided.
- Tailoring to local conditions: USC COCOMO II.1998 automates the process of calibrating COCOMO II to customize it to your local environment and process.

## References:

**Boehm95 -** "Cost Models for Future Software Life-cycle Processes: COCOMO 2.0," Boehm, B., B. Clark, E. Horowitz, C. Westland, R. Madachy, R. Selby, Annals of Software Engineering Special Volume on Software Process and Product Measurement, J.D. Arthur and S.M. Henry (Eds.), J.C. Baltzer AG, Science Publishers, Amsterdam, The Netherlands, Vol 1, 1995, pp. 45 - 60.

**Chulani98 -** “Calibrating Software Cost Models Using Bayesian Analysis”, Sunita Chulani, Barry Boehm and Bert Steece, Technical Report, USC-CSE-98-508, Jun ’98. To appear in IEEE Transactions on Software Engineering, Special Issue on Empirical Methods in Software Engineering.

**Kauffman93 -** "Modeling Estimation Expertise in Object Based ICASE Environments", Kauffman, R., and R. Kumar, Stern School of Business Report, New York University, January 1993.

**USC-CSE97 -** "COCOMO II Model Definition Manual," Center for Software Engineering, Computer Science Department, University of Southern California, Los Angeles, CA. 90007, website: http://sunset.usc.edu/COCOMOII/cocomo.html, 1997.

**USC COCOMO II.1998.0 can be downloaded from http://sunset.usc.edu/COCOMOII/suite.html.**

## Appendix: COCOMO II.1998 Parameters

This appendix has the acronyms and full forms of the 22 COCOMO II Post Architecture cost drivers and their associated COCOMO II.1998 numeric rating scale. For a further explanation of these parameters, please refer to [USC-CSE97]. The values of the base constants are A= 2.94, B= 0.91, C= 3.67, and D= 0.28.

| **Acronym** | **Parameter Name** | **Very Low** | **Low** | **Nominal** | **High** | **Very High** | **Extra High** |
|---|---|---|---|---|---|---|---|
| PREC | Precendentedness | 6.20 | 4.96 | 3.72 | 2.48 | 1.24 | 0.00 |
| FLEX | Development Flexibility | 5.07 | 4.05 | 3.04 | 2.03 | 1.01 | 0.00 |
| RESL | Architecture and Risk Resolution | 7.07 | 5.65 | 4.24 | 2.83 | 1.41 | 0.00 |
| TEAM | Team cohesion | 5.48 | 4.38 | 3.29 | 2.19 | 1.10 | 0.00 |
| PMAT | Process Maturity | 7.80 | 6.24 | 4.68 | 3.12 | 1.56 | 0.00 |
| RELY | Required Software Reliability | 0.82 | 0.92 | 1.00 | 1.10 | 1.26 | |
| DATA | Data Base Size | | 0.90 | 1.00 | 1.14 | 1.28 | |
| CPLX | Product Complexity | 0.73 | 0.87 | 1.00 | 1.17 | 1.34 | 1.74 |
| RUSE | Develop for Reuse | | 0.95 | 1.00 | 1.07 | 1.15 | 1.24 |
| DOCU | Documentation Match to Life-cycle Needs | 0.81 | 0.91 | 1.00 | 1.11 | 1.23 | |
| TIME | Time Constraint | | | 1.00 | 1.11 | 1.29 | 1.63 |
| STOR | Storage Constraint | | | 1.00 | 1.05 | 1.17 | 1.46 |
| PVOL | Platform Volatility | | 0.87 | 1.00 | 1.15 | 1.30 | |
| ACAP | Analyst Capability | 1.42 | 1.19 | 1.00 | 0.85 | 0.71 | |
| PCAP | Programmer Capability | 1.34 | 1.15 | 1.00 | 0.88 | 0.76 | |
| AEXP | Applications Experience | 1.22 | 1.10 | 1.00 | 0.88 | 0.81 | |
| PEXP | Platform Experience | 1.19 | 1.09 | 1.00 | 0.91 | 0.85 | |
| LTEX | Language and Tool Experience | 1.20 | 1.09 | 1.00 | 0.91 | 0.84 | |
| PCON | Personnel Continuity | 1.29 | 1.12 | 1.00 | 0.90 | 0.81 | |
| TOOL | Use of Software Tools | 1.17 | 1.09 | 1.00 | 0.90 | 0.78 | |
| SITE | Multi-Site Development | 1.22 | 1.09 | 1.00 | 0.93 | 0.86 | 0.80 |
| SCED | Required Development Schedule | 1.43 | 1.14 | 1.00 | 1.00 | 1.00 | |