بسم الله الرحمن الرحيم

in the Name of Allah, the Beneficient, the Merciful

Software Quality Assurance

Estimating Duration and Cost

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The Steps in Estimating

Step 1. Establish Cost-Estimation Objectives

Step 2. Develop a Plan for Estimation Activities; Plan for Resources

Step 3. Clarify Software Requirements

Step 4. Explore as Much Detail as Feasible

Step 5. Use Several Independent Techniques

Step 6. Compare, Understand, and Iterate Estimates

Step 7. Review Estimate Accuracy

COCOMO

- [Constructive Cost Model]
- Developed by Barry Bohem
- Modeled Cost, Effort and Schedule

COCOMO: A Regression Model

Regression Models in General

A regression model is derived from a statistical interpretation of historical data to describe a mean or "typical" relationship between variables.

Organic

The organic mode is typified by systems such as payroll, inventory, and scientific calculation. Other characterizations are that the project team is small, little innovation is required, constraints and deadlines are few, and the development environment is stable.

Semidetached

The semidetached mode is typified by utility systems such as compilers, database systems, and editors. Other characterizations are that the project team is medium-size, some innovation is required, constraints and deadlines are moderate, and the development environment is somewhat fluid.

Embedded

The embedded mode is typified by real-time systems such as those for air traffic control, ATMs, or weapon systems. Other characterizations are that the project team is large, a great deal of innovation is required, constraints and deadlines are tight, and the development environment consists of many complex interfaces, including those with hardware and with customers.

Table 11-1. COCOMO Mode Characteristics

Mode	Product Size	Project/Team Size	Innovation	Deadline and Constraints	Development Environment
Organic	Typically 2–50 KLOC	Small project, small team—development team is familiar with the application language and tools	Little	Not Tight	Stable, In-House
Semi-detached	Typically 50–300 KLOC	Medium project, medium team—team is average in terms of abilities	Medium	Medium	Medium
Embedded	Typically over 300 KLOC	Large project requiring a large team	Greater	Severe Constraints	Complex HW/Customer Interfaces

COCOMO Levels

Basic

This level uses only size and mode to determine the effort and schedule. It is useful for fast, rough estimates of small to medium-size projects.

Intermediate

This level uses size, mode, and 15 additional variables to determine effort. The additional variables are called "cost drivers" and relate to product, personnel, computer, and project attributes that will result in more effort or less effort required for the software project. The product of the cost drivers is known as the environmental adjustment factor (EAF).

Detailed

This level builds upon intermediate COCOMO by introducing the additional capabilities of phase-sensitive effort multipliers and a three-level product hierarchy. The intermediate level may be tailored to phase and product level to achieve the detailed level. An example of phase-sensitive effort multipliers would be consideration of memory constraints when attempting to estimate the coding or testing phases of a project. At the same time, though, memory size may not affect the effort or cost of the analysis phase. This will become more obvious after the effort multipliers (or cost drivers) are described. Phase-sensitive multipliers are generally reserved for use in mature organizations and require the use of an automated tool.

Basic COCOMO

- Basic COCOMO is good for quick estimate of software costs. However it does not account for differences in hardware constraints, personnel quality and experience, use of modern tools and techniques, and so on.

Basic COCOMO

Effort Estimation

KLOC is the only input variable. An exponential formula is used to calculate effort.

COCOMO Basic Effort Formula

Effort (E) = a x $(\text{Size})^b$

Where

a and b = constants derived from regression analysis (depends on the project)

Size = thousands of lines of code (KLOC)

E = effort expressed in staff-months

Basic COCOMO Effort Formulas for Three Modes

Effort for Organic Mode: $E = 2.4 \times (Size)^{1.05}$

Effort for Semidetached Mode: $E = 3.0 \times (Size)^{1.12}$

Effort for Embedded Mode: $E = 3.6 \times (Size)^{1.20}$

Table 11-2. Basic COCOMO Effort and Development Time Formulas

Mode	a	b	Effort Formula Effort = a x (Size) b	Development Time Formula
Organic	2.4	1.05	$E = 2.4 \times (S)^{1.05}$	$TDEV = 2.5 \times (E)^{0.38}$ Months
Semidetached	3.0	1.12	$E = 3.0 \times (S)^{1.12}$	$TDEV = 2.5 \times (E)^{0.35}$ Months
Embedded	3.6	1.20	$E = 3.6 \times (S)^{1.20}$	$TDEV = 2.5 \times (E)^{0.32}$ Months

Basic COCOMO Average Staff Estimate

When effort (E) and development time (TDEV) are known, the average staff size (SS) to complete the project may be calculated.

Average Staff: SS = Effort/TDEV

Basic COCOMO Average Staff and Productivity Estimation

The productivity level may be calculated.

Productivity: P = Size/Effort

Basic COCOMO Example 1

A development project is sized at 7.5 KLOC and is evaluated as being simple—in the organic mode.

The basic COCOMO equation for effort (E) in staff-months (SM) is:

Effort (SM) = $2.4(KLOC)^{1.05} = 2.4(7.5)^{1.05}$

$= 2.4(8.49296) = 20$ staff-months

Development time (TDEV):

TDEV = $2.5(SM)0.38 = 2.5(20)^{0.38} = 2.5(3.1217) = 8$ months

The average number of staff members (S):

Staff = Effort/TDEV = 20 staff-months/8 months

= 2.5 staff members on average

The productivity rate (P):

Productivity = Size/Effort = 7,500 LOC/ 20 staff-months

= 375 LOC/staff-month

Basic COCOMO Example 2

A development project is estimated to be about 55 KLOC when complete and is believed to be of medium complexity. It will be a Web-enabled system with a robust back-end database. It is assumed to be in the semidetached mode.

For a rough estimate of the effort that will be required to complete the project, use the formula:

E (effort in staff-months) = $3.0(\text{KLOC})^{1.12}$

E (effort in staff-months) = $3.0(55)^{1.12}$

E = 3.0(88.96)

E = 267 staff-months

Example 2 (cont)

To determine how long it will take to complete the project, use the formula:

TDEV = 2.5 x (E)0.35
TDEV = 2.5 x (267)0.35
TDEV = 2.5(7.07)
TDEV = 17.67 months

To obtain a rough estimate of how many developers will be needed, use the formula:
S (average staff) = effort÷TDEV
S (average staff) = 267÷17.67
S (average staff) = 15.11

To determine a rough estimate of the productivity rate, use the formula:
P (productivity) = size÷effort
P (productivity) = 55,000÷267
P (productivity) = 206 LOC/staff-month

Basic COCOMO Phase Distribution of Effort and Schedule

In addition to estimating development effort and schedule, it is often necessary to estimate how the effort is distributed among the primary life cycle activities. COCOMO takes a pretty simplistic view of the life cycle phases, considering only plans and requirements, product design, coding, and integration and test as the four development phases, and maintenance as the final life cycle phase.

Example of phase distribution of effort and schedule.

Let's look at an example of phase distribution of effort and schedule.

Suppose that an embedded mode project is sized at 80 KLOC.

E (effort in staff-months) = $3.6(\text{KLOC})^{1.20} = 3.6(80)^{1.20}$ = 3.6(192.18) = 692 staff-months

TDEV (development time) = 2.5(E)0.32 = 2.5(692)0.32 = 2.5(8.106) = 20 months

Table 11-3. Basic COCOMO Phase Distribution of Effort and Schedule Example, Where Estimated SM = 692 and Estimated TDEV = 20

	Plans and Requirements	Product Design	Coding	Integration and Test	Total
Effort (%) (% of effort spent in each major phase, based on historical data)	10%	12%	50.5%	27.5%	100% effort spread over four major phases
Effort (SM) = typical % of effort spent in this phase x estimated SM	.1 x 692 SM = 6.92 months	.12 x 692 SM = 83.04 months	.505 x 692 SM = 349.46 months	.275 x 692 SM = 190.3 months	692 months total staff-months
Schedule (%) (% of schedule spent on each major phase, based on historical data)	4%	33%	38%	25%	100% schedule spread over four major phases
Schedule (Months) = typical % of schedule spent on this phase x estimated TDEV	.04 x 20 = .8 months	.33 x 20 = 6.6 months	.38 x 20 = 7.6 months	.25 x 20 = 5 months	20 months duration (schedule)
Average # Personnel per major phase (Effort [SM]/Schedule [Months])	6.92÷.8 = 8.65 average persons	83.04÷6.6 = 12.5818 average persons	349.46÷7.6 = 45.98 average persons	190.3÷5 = 38.06 average persons	692÷20 = 34.6 average persons

Intermediate COCOMO

Intermediate COCOMO uses size and modes just like the basic model, plus 15 additional variables called cost drivers. The idea is that there are characteristics of a given project that drive the cost (effort) up or down.

Intermediate COCOMO Formula

Effort (E) = a x $(\text{Size})^b$ x C

Effort for Organic Mode: E = 3.2 x $(\text{Size})^{1.05}$ x C

Effort for Semidetached Mode: E = 3.0 x $(\text{Size})^{1.12}$ x C

Effort for Embedded Mode: E = 2.8 x $(\text{Size})^{1.20}$ x C

Cost Drivers

The concept of the effort adjustment factor (EAF) is that it has the effect of increasing or decreasing the effort, and therefore cost, depending on a set of environmental factors. These environmental factors are also known as cost adjustment factors [Cis], or cost drivers. There are two steps in determining this multiplying factor:

- **Step 1.** is to assign numerical values to the cost drivers.
- **Step 2.** is to multiply the cost drivers together to generate the effort adjustment factor, C.

When multiplied together, the cost adjustment factors can affect project cost and schedule estimates by 10 times or more!

Product of Cost Drivers Is the Effort Adjustment Factor

EAF = C1 x C2 x . . . x Cn

- Ci = 1 implies the cost driver does not apply
- Ci > 1 implies increased cost due to this factor
- Ci < 1 implies decreased cost due to this factor

Table 11-5. Intermediate COCOMO Cost Driver Categories

Product	Computer	Personnel	Project
Required Software Reliability (RELY)	Execution Time Constraint (TIME)	Analyst Capability (ACAP)	Use of Modern Programming Practices (MODP)
Database Size (DATA)	Main Storage Constraint (STOR)	Application Experience (AEXP)	Use of Software Tools (TOOL)
Product Complexity (CPLX)	Virtual Machine Volatility (VIRT)	Programmer Capability (PCAP)	Required Development Schedule (SCED)
	Computer Turnaround Time (TURN)	Virtual Machine Experience (VEXP)	
		Programming Language Experience (LEXP)	

Other Cost Drivers

Although product, computer, personnel, and project attributes are the four categories that are commonly associated with applications of the intermediate COCOMO model, additional attributes are often added by a project manager aware of other organizational (or project) strengths and/or weaknesses. Some common ones include:

- Requirements volatility—some is expected, but too much can be a big problem;
- Development machine volatility—unstable OS, compilers, CASE tools, and so on;
- Security requirements
- Access to data—sometimes very difficult;
- Impact of standards and imposed methods;
- Impact of physical surroundings.

Product of Cost Drivers

C = RELY x DATA x CPLX x TIME x STOR x VIRT x TURN x ACAP x AEXP x PCAP x VEXP x LEXP x MODP x TOOL x SCED

Table 11-6. Intermediate COCOMO Software Development Cost Driver Values

Cost Drivers	Ratings					
	Very Low	Low	Nominal	High	Very High	Extra High
Product Attributes						
Required Software Reliability (RELY)	.75	.88	1.00	1.15	1.40	
Database Size (DATA)		.94	1.00	1.08	1.16	
Product Complexity (CPLX)	.70	.85	1.00	1.15	1.30	1.65
Computer Attributes						
Execution Time Constraint (TIME)			1.00	1.11	1.30	1.66
Main Storage Constraint (STOR)			1.00	1.06	1.21	1.56
Virtual Machine Volatility (VIRT)		.87	1.00	1.15	1.30	
Computer Turnaround Time (TURN)		.87	1.00	1.07	1.15	
Personnel Attributes						
Analyst Capability (ACAP)	1.46	1.19	1.00	.86	.71	
Application Experience (AEXP)	1.29	1.13	1.00	.91	.82	
Programmer Capability (PCAP)	1.42	1.17	1.00	.86	.70	
Virtual Machine Experience (VEXP)	1.21	1.10	1.00	.90		
Programming Language Experience (LEXP)	1.14	1.07	1.00	.95		
Project Attributes						
Use of Modern Programming Practices (MODP)	1.24	1.10	1.00	.91	.82	
Use of Software Tools (TOOL)	1.24	1.10	1.00	.91	.82	
Required Development Schedule (SCED)	1.23	1.08	1.00	1.04	1.10	

Intermediate COCOMO Example 1

A 10 KLOC embedded-mode software product is to perform communications processing functions on a commercial microprocessor.

The embedded mode formula gives nominal effort:

$En = 2.8(10)^{1.20} = 2.8(15.85) = 44$ staff-months

An evaluation of the project environment yields choices for cost driver multiplier values

Table 11-12. (Continued) Cost Driver Values for the Intermediate COCOMO Example 1

Cost Driver	Situation	Rating	Effort Multiplier
RELY	Local use of system. No serious recovery problems.	Nominal	1.00
DATA	30,000 bytes.	Low	0.94
CPLX	Communications processing.	Very high	1.30
TIME	Will use 70% of available time.	High	1.11
STOR	45K of 64K store (70%).	High	1.06
VIRT	Based on commercial microprocessor hardware.	Nominal	1.00
TURN	2-hour average turnaround time.	Nominal	1.00
ACAP	Good senior analysts.	High	0.86
AEXP	3 years.	Nominal	1.00
PCAP	Good senior programmers.	High	0.86
VEXP	6 months.	Low	1.10
LEXP	12 months.	Nominal	1.00
MODP	Most techniques in use over 1 year.	High	0.91
TOOL	At basic minicomputer tool level.	Low	1.10
SCED	10 months.	Nominal	1.00
EAF	C = 1.00 x 0.94 x 1.30 x 1.11 x 1.06 x 1.00 x 1.00 x 0.86 x 1.00 x 0.86 x 1.10 x 1.00 x 0.91 x 1.10 x 1.00	C = 1.17	

Intermediate COCOMO Example 1 (cont)

The adjustment factor is applied to the nominal effort:

$E = 2.8(10)1.20 \times C = 44 \times 1.17 = 51$ staff-months

Intermediate COCOMO Example 2

Problem:

A project is estimated at 44 staff-months (SM). Using more capable personnel on the project decreases both the ACAP and PCAP ratings from nominal (1.00) to high (0.86), but the staff cost increases from $5,000 to $6,000 per SM. Assume that all other cost drivers are rated nominal (1.00).

Solution:

Effort Adjustment Factor (EAF) = C = RELY x DATA x CPLX x TIME x STOR x VIRT x TURN x ACAP x AEXP x PCAP x VEXP x LEXP x MODP x TOOL x SCED = 1.00 x 1.00 x 1.00 x 1.00 x 1.00 x 1.00 x 1.00 x 0.86 x 1.00 x 0.86 x 1.00 x 1.00 x 1.00 x 1.00 x 1.00 = 0.74

staff-month adjustment: 44 SM x 0.74 = 32.6

Intermediate COCOMO Example 2 (cont)

cost differential:	44 SM @ $5,000/SM = $220,000
	32.6 SM @ $6,000/SM = $195,600
	———— $ 24,400

Conclusion: In this example, upgrading of the personnel more than pays for itself in the form of overall project savings.