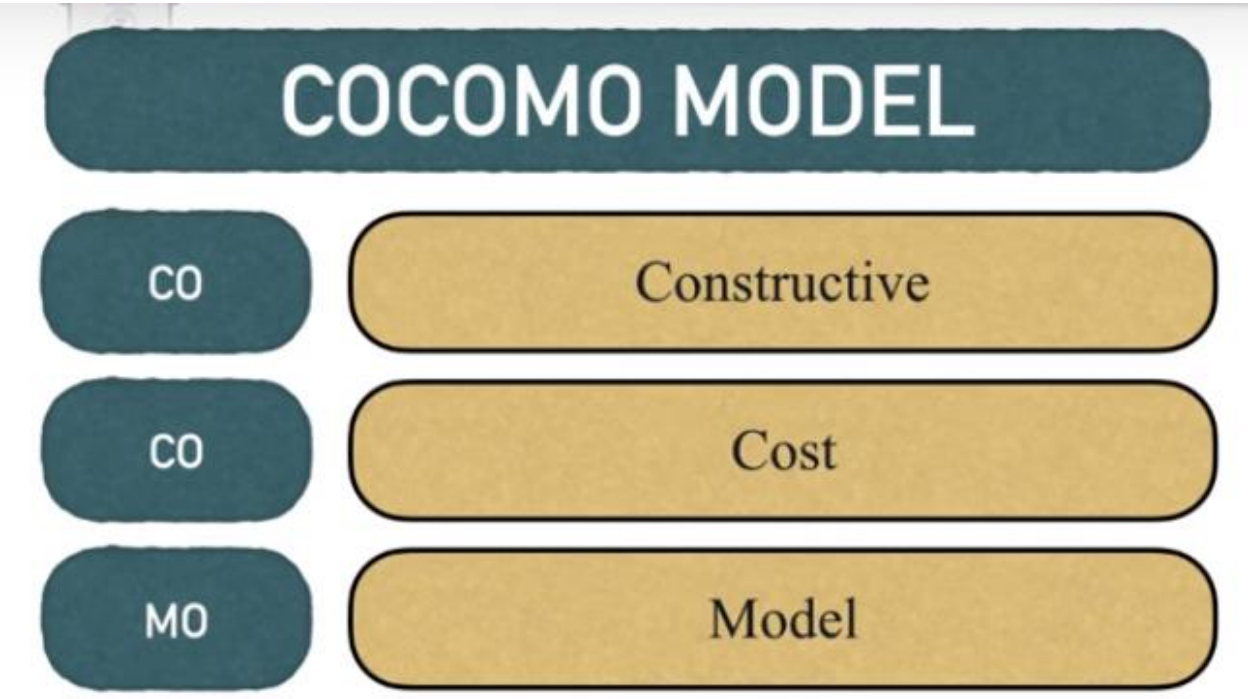
COCOMO Model

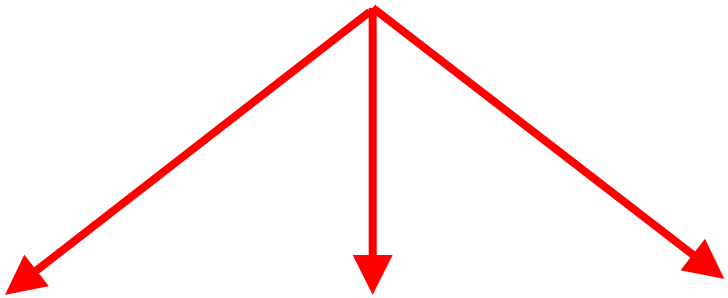


Outline of the talk

- **COCOMO Model**
- **Types of COCOMO Model**
- **COCOMO – II**

The Constructive Cost Model (COCOMO)

Constructive Cost model
(COCOMO)

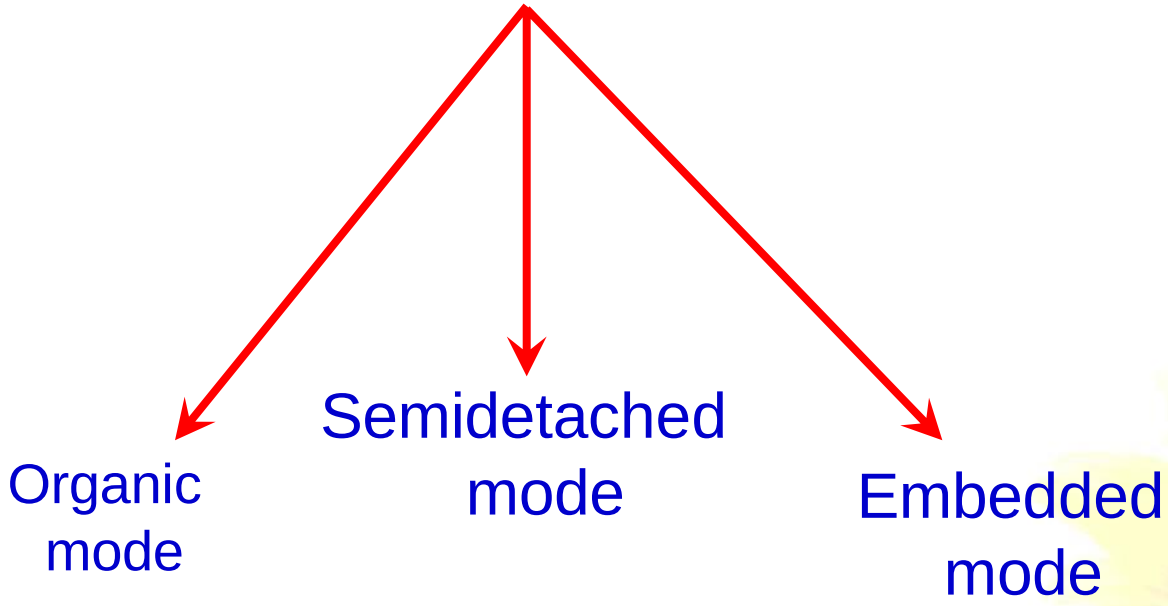


Basic Intermediate Detailed

Model proposed by
B. W. Boehm's through his book
Software Engineering Economics in 1981

Basic COCOMO MODEL

COCOMO applied to



Organic: Less Team Members, Problem is well understood, Solved In past

Semi-detached: Team is average, Problem is half solved, there is some experience

Embedded: Large teams, complex projects, experienced & creative members are required

Projects Types > Basic COCOMO MODEL

Mode	Project size	Nature of Project	Innovation	Deadline of the project	Development Environment
Organic	Typically 2-50 KLOC	Small size project, experienced developers in the familiar environment. For example, pay roll, inventory projects etc.	Little	Not tight	Familiar & In house
Semi detached	Typically 50-300 KLOC	Medium size project, Medium size team, Average previous experience on similar project. For example: Utility systems like compilers, database systems, editors etc.	Medium	Medium	Medium
Embedded	Typically over 300 KLOC	Large project, Real time systems, Complex interfaces, Very little previous experience. For example: ATMs, Air Traffic Control etc.	Significant	Tight	Complex Hardware/ customer Interfaces required

Table 4: The comparison of three COCOMO modes

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BASIC COCOMO MODEL

It estimates the software **roughly** and **quickly**. It is mostly useful for **small – medium** sized software.

- ORGANIC
- SEMI-DETACHED
- EMBEDED

Effort	=	$a\ (KLOC)^{b}$	Person-Month
Development Time	=	$c\ (Effort)^{d}$	Months
Average Staff Size	=	$Effort\ /\ Development\ Time$	Persons
Productivity	=	$KLOC\ /\ Effort$	KLOC / Person - Month

Basic Computes Software development effort & cost as function of Program Size

Basic COCOMO MODEL

Basic Model Only dependent on line of code LOC or KLOC

Basic COCOMO model takes the form

$$E = a_b (KLOC)^{b_b}$$

E= effort
D= development time

$$D = c_b (E)^{d_b}$$

where E is effort applied in Person-Months, and D is the development time in months. The coefficients a_b, b_b, c_b and d_b are given in table 4 (a).

Basic COCOMO MODEL

Software Project	a_b	b_b	c_b	d_b
Organic	2.4	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	3.6	1.20	2.5	0.32

Table 4(a): Basic COCOMO coefficients

Size & Productivity

When effort and development time are known, the average staff size to complete the project may be calculated as:

Average staff size $$(SS) = \frac{E}{D} Persons$$

When project size is known, the productivity level may be calculated as:

Productivity $$(P) = \frac{KLOC}{E} KLOC / PM$$

Basic COCOMO MODEL

Example: 4.5

Suppose that a project was estimated to be 400 KLOC. Calculate the effort and development time for each of the three modes i.e., organic, semidetached and embedded.

Software Project	a_b	b_b	c_b	d_b
Organic	2.4	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	3.6	1.20	2.5	0.32

Basic COCOMO MODEL

Solution

The basic COCOMO equation take the form:

$$E = a_b (KLOC)^{b_b}$$

$$D = c_b (E)^{d_b}$$

Estimated size of the project = 400 KLOC

(i) Organic mode

$E = 2.4(400)^{1.05} = 1295.31$ PM

$D = 2.5(1295.31)^{0.38} = 38.07$ PM

Basic COCOMO MODEL

(ii) Semidetached mode

$E = 3.0(400)^{1.12} = 2462.79$ PM

$D = 2.5(2462.79)^{0.35} = 38.45$ PM

(iii) Embedded mode

$E = 3.6(400)^{1.20} = 4772.81$ PM

$D = 2.5(4772.8)^{0.32} = 38$ PM

Basic COCOMO MODEL

Example: 4.6

A project size of 200 KLOC is to be developed. Software development team has average experience on similar type of projects. The project schedule is not very tight. Calculate the effort, development time, average staff size and productivity of the project.

Software Project	a_b	b_b	c_b	d_b
Organic	2.4	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	3.6	1.20	2.5	0.32

Basic COCOMO MODEL

Solution

The semi-detached mode is the most appropriate mode; keeping in view the size, schedule and experience of the development team.

Hence $E = 3.0(200)^{1.12} = 1133.12$ PM

$D = 2.5(1133.12)^{0.35} = 29.3$ PM

Average staff size $(SS) = \frac{E}{D} Persons$

$$= \frac{1133.12}{29.3} = 38.67 Persons$$

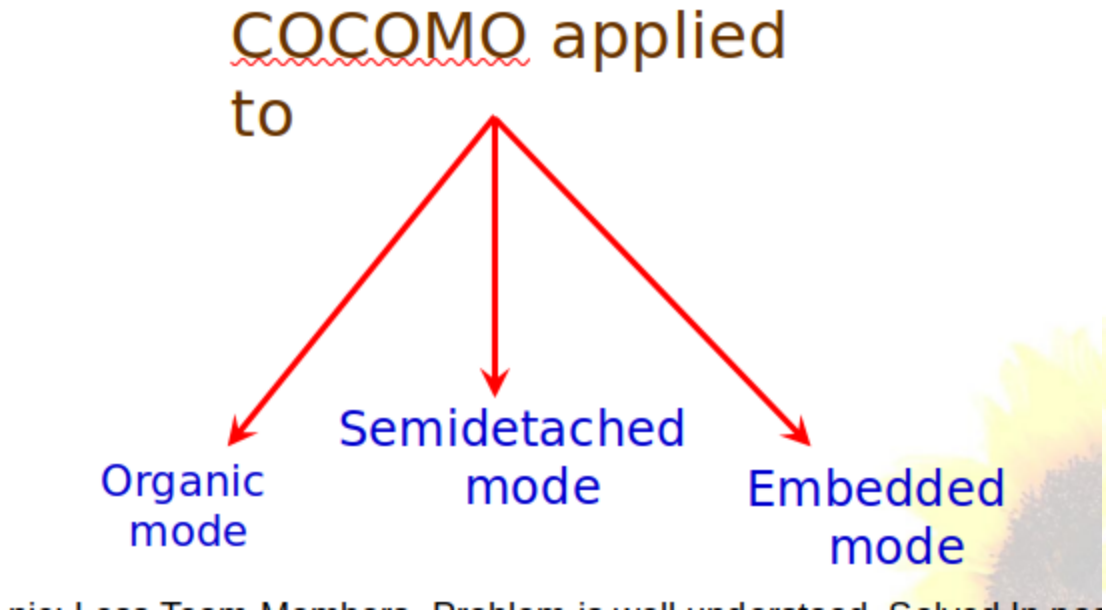
Basic COCOMO MODEL

Productivity $= \frac{KLOC}{E} = \frac{200}{1133.12} = 0.1765\ KLOC / PM$

$$P = 176\ LOC / PM$$

Intermediate Model

Intermediate Model Focus on Function of Program Size + Set of Cost Driver



Intermediate Model

Intermediate Model In basic cocomo only LOC factor was considered, but there are other factors as well that contribute in cost estimation, those 15 factors are added up in intermediate model

15 cost driver > First EAF (EFFORT ADJUSTMENT FACTOR), Effort, Duration

Cost drivers

i) Product Attributes

- Required s/w reliability > RELY
- Size of application database > DATA
- Complexity of the product > COMPLX

i) Hardware Attributes

- Run time performance constraints >TIME
- Memory constraints > STOR
- Virtual machine volatility > VIRT
- Turnaround time > TURN

Intermediate Model

(*iii*) **Personal Attributes**

- Analyst capability > ACAP
- Programmer capability> PAC
- Application experience > AEXP
- Virtual m/c experience > VEXP
- Programming language experience > LEXP

(*iv*)

- **Project Attributes**
- Modern programming practices > MODP
- Use of software tools > TOOL
- Required development Schedule > SCED

Intermediate Model >> 15 Factors

Multipliers of different cost drivers

Cost Drivers	RATINGS					
	Very low	Low	Nominal	High	Very high	Extra high
Product Attributes						
RELY	0.75	0.88	1.00	1.15	1.40	--
DATA	--	0.94	1.00	1.08	1.16	--
CPLX	0.70	0.85	1.00	1.15	1.30	1.65
Computer Attributes						
TIME	--	--	1.00	1.11	1.30	1.66
STOR	--	--	1.00	1.06	1.21	1.56
VIRT	--	0.87	1.00	1.15	1.30	--
TURN	--	0.87	1.00	1.07	1.15	--

Intermediate Model >> 15 Factors

Cost Drivers	RATINGS					
	Very low	Low	Nominal	High	Very high	Extra high
Personnel Attributes						
ACAP	1.46	1.19	1.00	0.86	0.71	--
AEXP	1.29	1.13	1.00	0.91	0.82	--
PCAP	1.42	1.17	1.00	0.86	0.70	--
VEXP	1.21	1.10	1.00	0.90	--	--
LEXP	1.14	1.07	1.00	0.95	--	--
Project Attributes						
MODP	1.24	1.10	1.00	0.91	0.82	--
TOOL	1.24	1.10	1.00	0.91	0.83	--
SCED	1.23	1.08	1.00	1.04	1.10	--

Table 5: Multiplier values for effort calculations

Intermediate Model

Intermediate COCOMO equations

Estimation Adjustment Factor

$$E = a_i (KLOC)^{b_i} * EAF$$

$$D = c_i (E)^{d_i}$$

Project	a_i	b_i	c_i	d_i
Organic	3.2	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	2.8	1.20	2.5	0.32

Table 6: Coefficients for intermediate COCOMO

Example: For a given project was estimated with a size of 300 KLOC. Calculate the Effort, Scheduled time for development by considering developer having high application experience and very low experience in programming.

Ans:

Given the estimated size of the project is: 300 KLOC
Developer having highly application experience: 0.82 (as per above table)
Developer having very low experience in programming: 1.14(as per above table)

EAF = 0.82*1.14 = 0.9348
Effort (E) = $a*(KLOC)^{b}$ *EAF = $3.0*(300)^{1.12}$ *0.9348 = 1668.07 MM
Scheduled Time (D) = $c*(E)^{d}$ = $2.5*(1668.07)^{0.35}$ = 33.55 Months(M)

Example: 4.7

A new project with estimated 400 KLOC embedded system has to be developed. Project manager has a choice of hiring from two pools of developers: Very highly capable with very little experience in the programming language being used

Or

Developers of low quality but a lot of experience with the programming language. What is the impact of hiring all developers from one or the other pool ?

Project	a_i	b_i	c_i	d_i
Organic	3.2	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	2.8	1.20	2.5	0.32

Table 6: Coefficients for intermediate COCOMO

Solution

This is the case of embedded mode and model is intermediate COCOMO.

Hence $E = a_i (KLOC)^{b_i} * EAF$

E = 2.8 $(400)^{1.20}$ = 3712 PM

Case I: Developers are very highly capable with very little experience in the programming being used.

EAF = 0.82 x 1.14 = 0.9348

E = 3712 x .9348 = 3470 PM

D = 2.5 $(3470)^{0.32}$ = 33.9 M

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Cost Drivers	RATINGS					
	Very low	Low	Nominal	High	Very high	Extra high
Personnel Attributes						
ACAP	1.46	1.19	1.00	0.86	0.71	--
AEXP	1.29	1.13	1.00	0.91	0.82	--
LEXP	1.14	1.07	1.00	0.95	--	--

Case II: Developers are of low quality but lot of experience with the programming language being used.

EAF = 1.29 x 0.95 = 1.22

E = 3712 x 1.22 = 4528 PM

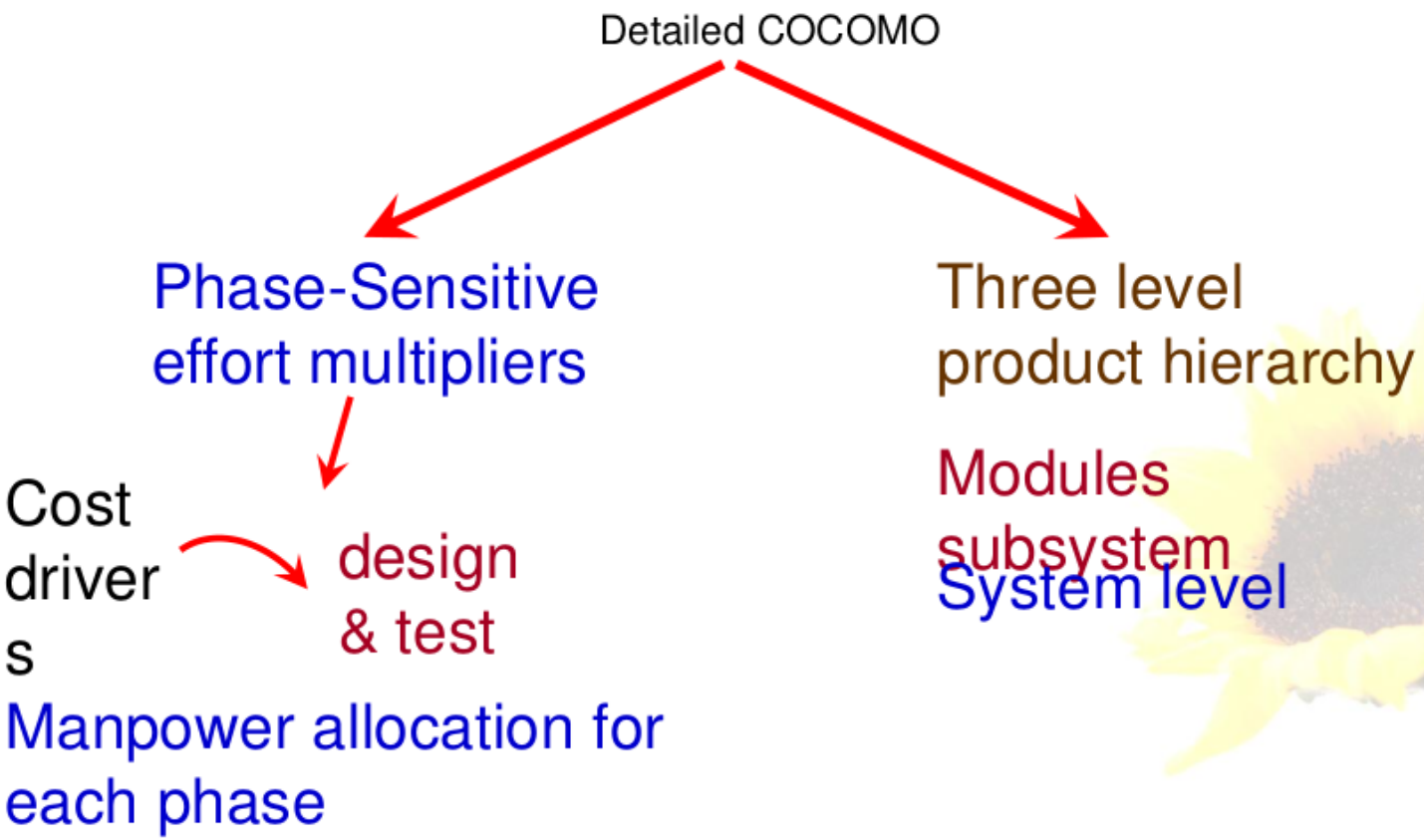
D = $2.5 (4528)^{0.32}$ = 36.9 M

Case II requires more effort and time. Hence, low quality developers with lot of programming language experience could not match with the performance of very highly capable developers with very litter experience.

Detailed Model

Advance all characteristics of Intermediate + Cost Drivers Impact on Each Step, Detailed cocomo focus on Effort & Development Time w.r.t Phase

Detailed COCOMO Model



Detailed Model

Development Phase

Plan / Requirements

EFFORT	:	6% to 8%
DEVELOPMENT TIME	:	10% to 40%

% depend on mode & size

Detailed Model

Design

Effort	:	16% to 18%
Time	:	19% to 38%

Programming

Effort	:	48% to 68%
Time	:	24% to 64%

Integration & Test

Effort	:	16% to 34%
Time	:	18% to 34%

Detailed COCOMO

Detailed cocomo focus on Effort & Development Time w.r.t Phase

In detailed COCOMO all the factors & criteria that have dependency on calculation of cost is covered.

Complete software is divided in to modules & then by applying COCOMO to each modules & effort as calculated & then later all the sums are added

Detailed COCOMO > Phases of Detailed COCOMO

Distribution of software life cycle:

1. **Requirement and product design**
   a) **Plans and requirements**
   (b) **System design**

1. **Detailed Design**
   a) **Detailed design**

1. **Code & Unit test**
   a) **Module code & test**

1. **Integrate and Test**
   a) **Integrate & Test**

Detailed COCOMO

Principle of the effort estimate

Size equivalent

As the software might be partly developed from software already existing (that is, re-usable code), a full development is not always required. In such cases, the parts of design document (DD%), code (C%) and integration (I%) to be modified are estimated. Then, an adjustment factor, A, is calculated by means of the following equation.

$$A = 0.4\,DD + 0.3\,C + 0.3\,I$$

The size equivalent is obtained by

$$S\ (\text{equivalent}) = (S \times A) / 100$$

$$E_p = \mu_p E$$

$$D_p = \tau_p D$$

$$E = a_i (KLOC)^{b_i} * EAF$$

$$D = c_i (E)^{d_i}$$

$$E_p = \mu_p E$$

$$D_p = \tau_p D$$

E= effort
D= development time

Detailed COCOMO

Lifecycle Phase Values of μ_p

Mode & Code Size	Plan & Requirements	System Design	Detailed Design	Module Code & Test	Integration & Test
Organic Small S≈2	0.06	0.16	0.26	0.42	0.16
Organic medium S≈32	0.06	0.16	0.24	0.38	0.22
Semidetached medium S≈32	0.07	0.17	0.25	0.33	0.25
Semidetached large S≈128	0.07	0.17	0.24	0.31	0.28
Embedded large S≈128	0.08	0.18	0.25	0.26	0.31
Embedded extra large S≈320	0.08	0.18	0.24	0.24	0.34

Table 7 : Effort and schedule fractions occurring in each phase of the lifecycle

Detailed COCOMO

Lifecycle Phase Values of τ_p

Mode & Code Size	Plan & Requirements	System Design	Detailed Design	Module Code & Test	Integration & Test
Organic Small S≈2	0.10	0.19	0.24	0.39	0.18
Organic medium S≈32	0.12	0.19	0.21	0.34	0.26
Semidetached medium S≈32	0.20	0.26	0.21	0.27	0.26
Semidetached large S≈128	0.22	0.27	0.19	0.25	0.29
Embedded large S≈128	0.36	0.36	0.18	0.18	0.28
Embedded extra large S≈320	0.40	0.38	0.16	0.16	0.30

Table 7 : Effort and schedule fractions occurring in each phase of the lifecycle

Detailed COCOMO

Example: 4.8

Consider a project to develop a full screen editor. The major components identified are:

I. Screen edit

II. Command Language Interpreter

III. File Input & Output

IV. Cursor Movement

V. Screen Movement

The size of these are estimated to be 4k, 2k, 1k, 2k and 3k delivered source code lines. Use COCOMO to determine

1. Overall cost and schedule estimates (assume values for different cost drivers, with at least three of them being different from 1.0)
2. Cost & Schedule estimates for different phases.

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Assume that significant cost drivers are

i. Required software reliability is high, i.e.,1.15

i. Product complexity is high, i.e.,1.15

i. Analyst capability is high, i.e.,0.86

i. Programming language experience is low,i.e.,1.07

ii. All other drivers are nominal (mean they are 1)

Here values for 5 cost drivers is given, This Value if given find it from table eg Analyst Capability (ACAP) is hight etc.

But for the case where these values are not specified take all Cost Driver values as 1

Detailed COCOMO

Solution

Size of five modules are:

Screen edit	= 4 KLOC
Command language interpreter	= 2 KLOC
File input and output	= 1 KLOC
Cursor movement Screen movement	= 2 KLOC
Total	= 3 KLOC
	= 12 KLOC

Let us assume that significant cost drivers are

Cost Drivers	RA		
	Very low	Low	Nomina
Product Attributes			
RELY	0.75	0.88	1.00
DATA	--	0.94	1.00
CPLX	0.70	0.85	1.00

i. Required software reliability is high, i.e.,1.15

i. Product complexity is high, i.e.,1.15

i. Analyst capability is high, i.e.,0.86

i. Programming language experience is low,i.e.,1.07

ii. All other drivers are nominal (mean they are 1)

EAF = 1.15x1.15x0.86x1.07 = 1.2169

Cost Drivers	RATINGS					
	Very low	Low	Nominal	High	Very high	Extra high
Personnel Attributes						
ACAP	1.46	1.19	1.00	0.86	0.71	--
AEXP	1.29	1.13	1.00	0.91	0.82	--
PCAP	1.42	1.17	1.00	0.86	0.70	--
VEXP	1.21	1.10	1.00	0.90	--	--
LEXP	1.14	1.07	1.00	0.95	--	--

Detailed COCOMO

(a) The initial effort estimate for the project is obtained from the following equation

Organic $E = a_i (KLOC)^{bi} \times EAF$

$= 3.2(12)^{1.05} \times 1.2169 = 52.91$ PM

Development time $D = C_i(E)^{di}$

$= 2.5(52.91)^{0.38} = 11.29$ M

(b) Using the following equations and referring Table 7, phase wise cost and schedule estimates can be calculated.

$$E_p = \mu_p E$$

$$D_p = \tau_p D$$

Project	a_i	b_i	c_i	d_i
Organic	3.2	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	2.8	1.20	2.5	0.32

Table 6: Coefficients for intermediate COCOMO

Lifecycle Phase Values of μ_p

Mode & Code Size	Plan & Requirements	System Design	Detailed Design	Module Code & Test	Integration & Test
Organic Small S≈2	0.06	0.16	0.26	0.42	0.16
Organic medium S≈32	0.06	0.16	0.24	0.38	0.22

Lifecycle Phase Values of τ_p

Mode & Code Size	Plan & Requirements	System Design	Detailed Design	Module Code & Test	Integration & Test
Organic Small S≈2	0.10	0.19	0.24	0.39	0.18
Organic medium S≈32	0.12	0.19	0.21	0.34	0.26

In question it will be specified that μ is for Organic small S≈2 or Organic Medium S≈32

Detailed COCOMO

Since size is only 12 KLOC, it is an organic small model. Phase wise effort distribution is given below:

effort

System Design	= 0.16 x 52.91 = 8.465 PM
Detailed Design	= 0.26 x 52.91 = 13.756 PM
Module Code & Test	= 0.42 x 52.91 = 22.222 PM
Integration & Test	= 0.16 x 52.91 = 8.465 Pm

Now Phase wise development time duration is

Development

System Design	= 0.19 x 11.29 = 2.145 M
Detailed Design	= 0.24 x 11.29 = 2.709 M
Module Code & Test	= 0.39 x 11.29 = 4.403 M
Integration & Test	= 0.18 x 11.29 = 2.032 M

Detailed COCOMO

COCOMO-II

The following categories of applications / projects are identified by COCOMO-II and are shown in fig. 4 shown below:

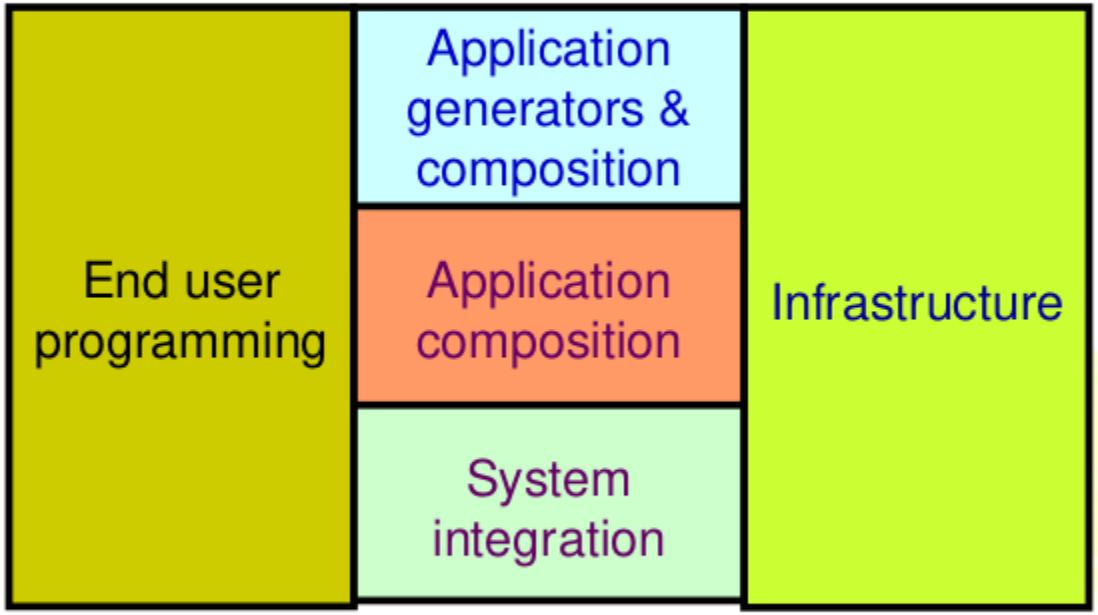

Fig. 4 : Categories of applications / projects

Detailed COCOMO

Stage No	Model Name	Application for the types of projects	Applications
Stage I	Application composition estimation model	Application composition	In addition to application composition type of projects, this model is also used for prototyping (if any) stage of application generators, infrastructure & system integration.
Stage II	Early design estimation model	Application generators, infrastructure & system integration	Used in early design stage of a project, when less is known about the project.
Stage III	Post architecture estimation model	Application generators, infrastructure & system integration	Used after the completion of the detailed architecture of the project.

Table 8: Stages of COCOMO-II

COCOMO NUMERICAL

Suppose that a project was estimated to be 4 million LOC. Calculate effort & time for each of 3 modes of development.

Type	*a*	*b*	*c*	*d*
Organic	*2.4*	*1.05*	*2.5*	*0.38*
Semi-detached	*3.0*	*1.12*	*2.5*	*0.35*
Embeded	*3.6*	*1.20*	*2.5*	*0.32*

SOLUTION

As we know that the 3 modes of development are

1. *Organic*
2. *Semi-detached*
3. *Embeded*

Also we know that

Effort $= a\ (KLOC)^{b}$ *Person-Month*

Development Time $= c\ (Effort)^{d}$ *Months*

Here, we are given LOC = 400000

Therefore, KLOC = 400

1. Organic

KLOC = 400

a = 2.4 b = 1.05 c = 2.5 d = 0.38

Effort

$$= a\,(KLOC)^{b} \quad \textit{Person-Month}$$

$$= 2.4\,(400)^{1.05} \quad \textit{Person-Month}$$

$$\approx 1295 \quad \textit{Person-Month}$$

Development Time

$$= c\,(Effort)^{d} \quad \textit{Months}$$

$$= 2.5\,(1295)^{0.38} \quad \textit{Months}$$

$$\approx 38 \quad \textit{Months}$$

2. Semi-detacheed

KLOC = 400 | a = 3 b = 1.12 c = 2.5 d = 0.35

Effort

$$= a\,(KLOC)^{b} \quad \textit{Person-Month}$$
$$= 3\,(400)^{1.12} \quad \textit{Person-Month}$$
$$\approx 2462 \quad \textit{Person-Month}$$

Development Time

$$= c\,(Effort)^{d} \quad \textit{Months}$$
$$= 2.5\,(2462)^{0.35} \quad \textit{Months}$$
$$\approx 38.4 \quad \textit{Months}$$

3. Embeded

KLOC = 400

a = 3.6 b = 1.2 c = 2.5 d = 0.32

Effort

$$= a\,(KLOC)^{b} \quad \textit{Person-Month}$$

$$= 3.6\,(400)^{1.2} \quad \textit{Person-Month}$$

$$\approx 4772 \quad \textit{Person-Month}$$

Development Time

$$= c\,(Effort)^{d} \quad \textit{Months}$$

$$= 2.5\,(4772)^{0.32} \quad \textit{Months}$$

$$\approx 38$$

Research Work

- **Cost *Models* for Future Software Life Cycle Processes: *COCOMO* 2**