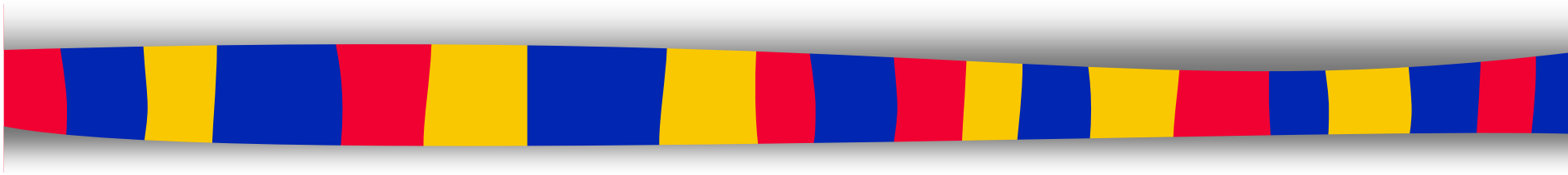
EECS 4314
Advanced Software Engineering



Topic 12:
Software Cost Estimation

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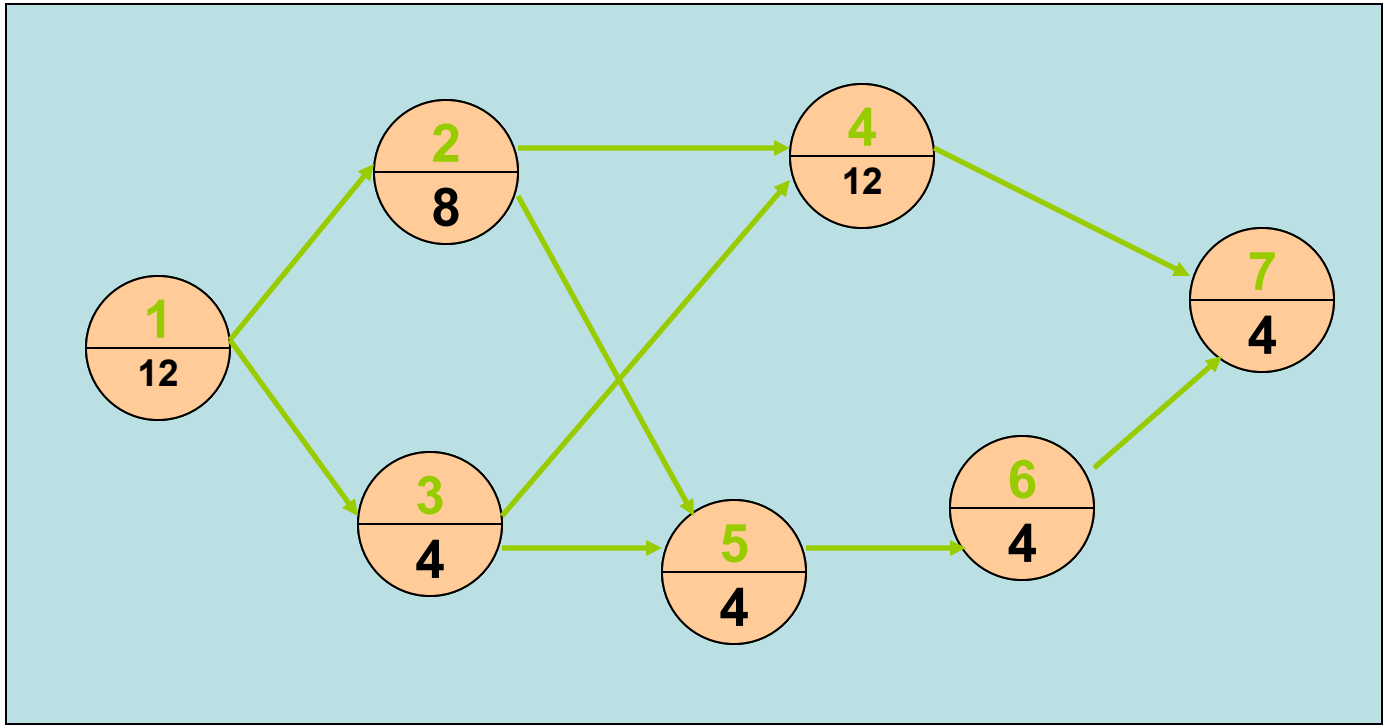
Slides Adapted from Ian Sommerville

Why Cost Estimation?



Why Cost Estimation?

- Need to establish a budget
- Need to set a price
- Need to make a profit

- Software cost estimation predicts the resources the required for a software development process

Cost Estimation

- Cost estimation and scheduling are usually done together
- Cost is driven by three main activities:
  - HW and SW costs, including maintenance
  - Travel and training (can be reduced using technology)
  - Effort costs (paying personnel)
- For most projects **effort costs** is the dominant cost

Effort Costs

- Effort costs are more than just salaries
  - E.g., heat, lighting, support staff, networking, recreational facilities, security, etc…
- Effort cost is calculated by taking the total cost of running the organization and dividing by number of productive staff
- How much does overhead cost?

Cost Estimation Topics

- Productivity
- Estimation Techniques
- Algorithmic Cost Estimation
- Project Duration Staffing

Software Productivity

- Generally, productivity is measured as:
  - Number of units / person hours
- Not the case in software…why?
  - It can have many solutions
    - Solution 1: executes more efficiently
    - Solution 2: easier to read and maintain

Software Productivity

- Based on measuring attributes of the software divided by total development effort
- Size related:
  - LOC delivered
- Function related:
  - Function points (FP) and object points (OP)

Size related metrics

- LOC per programmer-month (LOC/pm)
- This time includes requirements, design, coding, testing, documentation
- **Advantage**: Easy to calculate
- **Disadvantage**: different languages
  - E.g., 5000 assembly ~ 1500 C

Function Related Metrics

- Productivity = FP/pm
- FP is related to:
  - External and internal inputs
  - User interactions
  - External interfaces
  - Files used by the system
- Functionality is independent of implementation language

Function Points

- Some input and output interactions, etc. are more complex than others
- You can give a weight to the FP, considering:
  - Amount of reuse, performance, etc. …
- FP count is highly subjective and depends on the estimator!
- FPs are biased towards data-processing systems

Object Points

- Object points are an alternative to FPs
- The number of object points is a weighted estimate of:
  - No. of separate screens displayed (1,2,3)
  - No. of reports produced (2,5,8)
  - No. of modules that must be developed to support 4th generation language code

FP and OP

- OP are easier to estimate. They only consider screens, reports and modules
- OP can be estimated early in the development process
- OP can approximate LOC from FP or OP:
  - LOC = AVC x No. of FP
  - AVC is 200-300 LOC/FP in assembly language and 2 - 40 LOC in 4 GL

Productivity Estimates

- Many factors impact productivity
  - Some programmers are 10 times more productive
  - Application domain:
    - Embedded systems: ~30 LOC/pm
    - Application systems: ~900 LOC/pm
    - 4-50 OP/pm, depending on application, tools, developers
  - Process, project size, technology support, working environment

LOC doesn't impress me much!

- Counting LOC does not take into account:
  - Reused code
  - Generated code
  - Quality
  - Performance
  - Maintainability
- Not clear how productivity and quality metrics are related!

Estimation Techniques

- There is no simple way to make accurate estimates of the effort required
  - Initially, not much detail is given
  - Technologies and people may be unknown
- Project cost estimates may be self-fulfilling
  - Estimate defines budget, project adjusted to meet budget

Many Estimation Techniques

- Algorithmic cost modeling
- Expert judgment
- Estimation by analogy
- Parkinson's Law
- Pricing to win

Algorithmic code modelling

- Model is built based on historical cost information
- Generally based on the size of the software

Expert judgement

- Several experts in software development and the application domain are consulted
- Process iterates until some consensus is reached
- **Advantages**: Relatively cheap estimation method. Can be accurate if experts have direct experience of similar systems
- **Disadvantages**: Very inaccurate if there are no experts!

Estimation by analogy

- The project is compared to a similar project in the same application domain
- **Advantages**: Accurate if project data available
- **Disadvantages**: Impossible if no comparable project has been tackled

Parkinson's Law

- “Work expands to fill the time available” i.e., the project costs whatever resources are available
- **Advantages**: No overspending
- **Disadvantages**: System is usually unfinished

Pricing to win

- The project costs whatever the customer has to spend on it
- **Advantages**: You get the contract
- **Disadvantages**: The probability that the customer gets the system he or she wants is small. Often, costs do not accurately reflect the work required

Cost Estimation Approaches

- The aforementioned techniques may be used top-down or bottom-up
- **Top-down**: Starts at the system level and assess system functionality and its delivery through subsystems
- **Bottom-up**: Start at component level and aggregate to obtain system effort

Top-down vs. Bottom-up

- Top-down:
  - Usable without much knowledge
  - Factors in integration, configuration and documentation costs
  - Can underestimate low-level problems
- Bottom-up:
  - Usable when architecture of the system is known
  - May underestimate system-level activities such as integration

Algorithmic Cost Modeling

Algorithmic Cost Modeling

- A cost model can be built by analyzing the cost and attributes of similar projects

- **Effort** = A x $Size^B$ x M
  - **A** – depends on organization
  - **B** – ~1-1.5 reflects disproportionate effort for large projects (communication and configuration management)
  - **M** – reflects product, process and people attributes

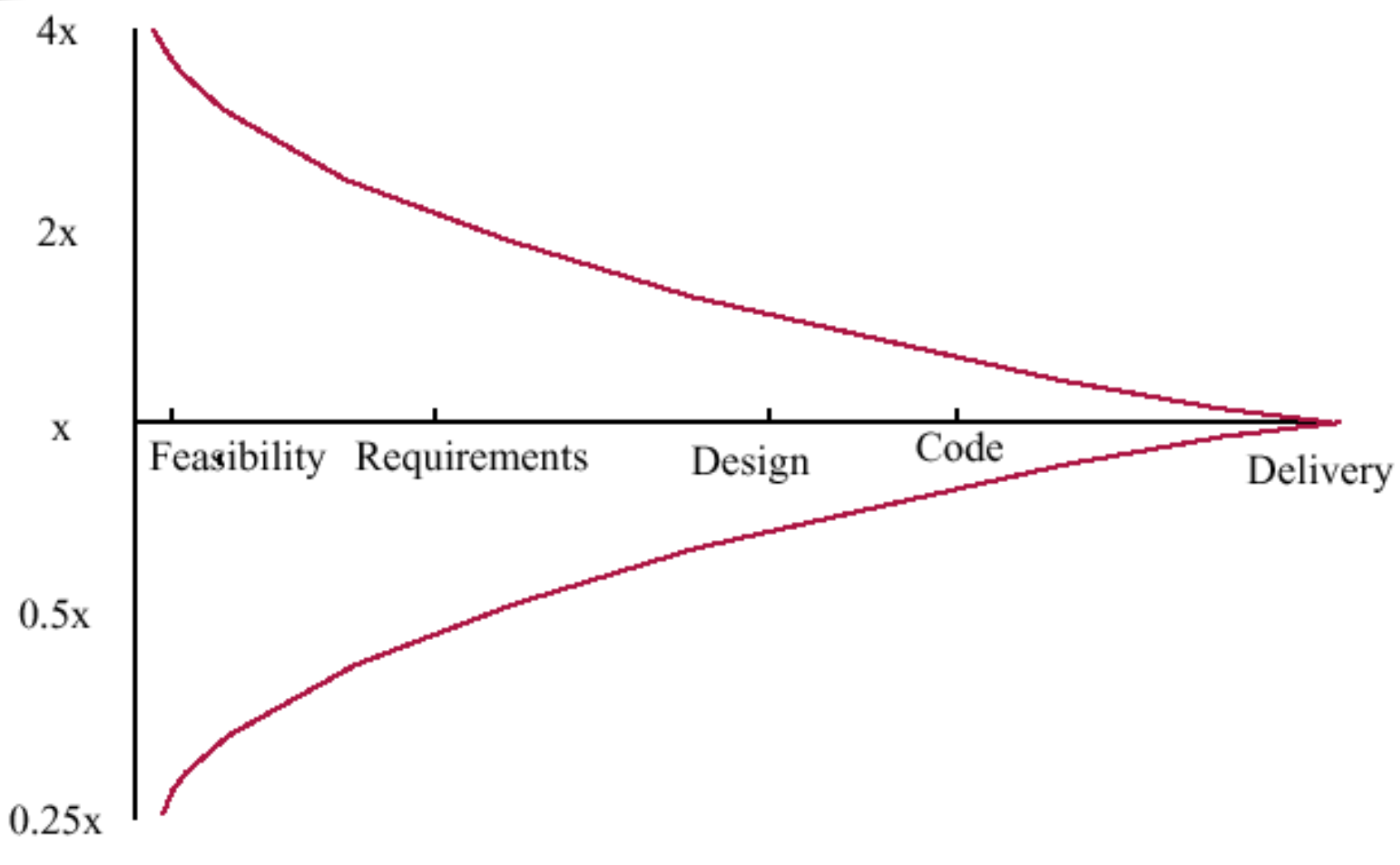
- Most models are similar but with different values for A, B and M

Estimation Accuracy

- Difficult to estimate size early on. The values for B and M are subjective
- Several factors influence the final size
  - Use of COTS (Commercial Off-the-Shelf) and components
  - Programming language
- Estimations become more accurate as development progresses

[Sommerville 2000]

Estimate uncertainty



COCOMO Model

- COCOMO stands for *Constructive Cost Modeling*
- Empirical model based on project experience
  - Derived by collecting data from a large number of software projects of different sizes
- Started with COCOMO-81 and later revised to COCOMO 2
- COCOMO 2 is very detailed and takes into account different approaches, reuse, etc. …

COCOMO 81

Project complexity	Formula	Description
Simple	$PM = 2.4\ (KDSI)^{1.05} \times M$	Well-understood applications developed by small teams.
Moderate	$PM = 3.0\ (KDSI)^{1.12} \times M$	More complex projects where team members may have limited experience of related systems.
Embedded	$PM = 3.6\ (KDSI)^{1.20} \times M$	Complex projects where the software is part of a strongly coupled complex of hardware, software, regulations and operational procedures.

A – depends on organization
B – reflects disproportionate effort for large projects
M - reflects product, process and people attributes

COCOMO 2 levels

- **Early prototyping model**
  - Estimates based on OP and a simple formula
- **Early design model**
  - Estimates based on FP that are translated to LOC
- **Reuse model**
  - Estimates effort to integrate reused and generated code
- **Post-architecture level**
  - Estimates based on lines of source code

Early Prototyping Level

- Supports prototyping projects and projects where **software is developed by composing existing components**

- PM = (NOP x (1 - %reuse/100)) / PROD
  - **PM** is the effort in person-months
  - **NOP** is the number of object points
  - **PROD** is the productivity

Object point productivity

Developer's experience and capability	Very low	Low	Nominal	High	Very high
ICASE maturity and capability	Very low	Low	Nominal	High	Very high
PROD (NOP/month)	4	7	13	25	50

Early design level

- Estimates can be made after requirements
- Based on standard algorithmic model
  - $PM = A \times Size^{B} \times M$
    - A = 2.94 in initial calibration
    - Size in KLOC (approximated from FP)
    - B varies from 1.01 to 1.26 depending on novelty, development flexibility, risk management and the process maturity
    - M = PERS x RCPX x RUSE x PDIF x PREX x FCIL x SCED

Multipliers

- Multipliers developers, non-functional requirements, development platform, etc.
  - PERS - personnel **capability**
  - RCPX - product **reliability** and **complexity**
  - RUSE - the **reuse** required
  - PDIF - **platform** difficulty
  - PREX - personnel **experience**
  - SCED - required **schedule**
  - FCIL - the team support **facilities**

The Reuse Model

- Effort is required to integrate automatically generated code
- PM_{Auto} = (ASLOC x (AT/100)) / ATPROD
  - ASLOC – Number of LOC that have to be adapted
  - AT - % of adapted code that is automatically generated
  - ATPROD – engineer productivity in adapting code (2400 LOC/month)
- Example: 20,000 LOC, 30% automatically generated
  - (20,000 x 30/100) / 2400 = 2.5 pm

Post-architecture level

- Uses same formula as early design estimates ($PM = A \times Size^{B} \times M$)
- Size estimate for the software should be more accurate at this stage. Takes into consideration:
  - **New code** to be developed
  - **Rework** required to support change
  - Extent of possible **reuse**

The exponent term (B)

- This depends on 5 scale factors (very low – extra high 5-0). Their sum/100 is added to 1.01

Scale factor	Explanation
Precedentedness	Reflects the previous experience of the organisation with this type of project. Very low means no previous experience, Extra high means that the organisation is completely familiar with this application domain.
Development flexibility	Reflects the degree of flexibility in the development process. Very low means a prescribed process is used; Extra high means that the client only sets general goals.
Architecture/risk resolution	Reflects the extent of risk analysis carried out. Very low means little analysis, Extra high means a complete a thorough risk analysis.
Team cohesion	Reflects how well the development team know each other and work together. Very low means very difficult interactions, Extra high means an integrated and effective team with no communication problems.
Process maturity	Reflects the process maturity of the organisation. The computation of this value depends on the CMM Maturity Questionnaire but an estimate can be achieved by subtracting the CMM process maturity level from 5.

The Exponent Term (B) Example

- Example:
  - Precedentedness
    - new project (4), rated low
  - Development flexibility
    - no client involvement, (1) Very high
  - Architecture/risk resolution
    - No risk analysis, (5) Very Low
  - Team cohesion
    - new team, (3) nominal
  - Process maturity
    - some control, (3) nominal
- Scale factor is therefore 1.17
  - (4 + 1 + 5 + 3 + 3) / 100 + 1.01 = 1.17

Multipliers (M)

Attribute	Type	Description
RELY	Product	Required system reliability
CPLX	Product	Complexity of system modules
DOCU	Product	Extent of documentation required
DATA	Product	Size of database used
RUSE	Product	Required percentage of reusable components
TIME	Computer	Execution time constraint
PVOL	Computer	Volatility of development platform
STOR	Computer	Memory constraints
ACAP	Personnel	Capability of project analysts
PCON	Personnel	Personnel continuity
PCAP	Personnel	Programmer capability
PEXP	Personnel	Programmer experience in project domain
AEXP	Personnel	Analyst experience in project domain
LTEX	Personnel	Language and tool experience
TOOL	Project	Use of software tools
SCED	Project	Development schedule compression
SITE	Project	Extent of multisite working and quality of inter-site communications

- Product attributes
  - required **characteristics of the software** product being developed
- Computer attributes
  - **constraints** imposed on the **software** by the **hardware** platform
- Personnel attributes
  - multipliers that take the **experience** and **capabilities** of the people working on the project into account
- Project attributes
  - concerned with the particular **characteristics** of the **software development** project

Values (0.5-1.5)

Effects of cost drivers

Exponent value	1.17
System size (including factors for reuse and requirements volatility)	128, 000 DSI
Initial COCOMO estimate without cost drivers	**730 person-months**

Effects of cost drivers

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Initial COCOMO estimate without cost drivers	**730 person-months**
Reliability	Very high, multiplier = 1.39
Complexity	Very high, multiplier = 1.3
Memory constraint	High, multiplier = 1.21
Tool use	Low, multiplier = 1.12
Schedule	Accelerated, multiplier = 1.29
Adjusted COCOMO estimate	**2306 person-months**

Effects of cost drivers

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System size (including factors for reuse and requirements volatility)	128, 000 DSI
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Tool use	Low, multiplier = 1.12
Schedule	Accelerated, multiplier = 1.29
Adjusted COCOMO estimate	**2306 person-months**
Reliability	Very low, multiplier = 0.75
Complexity	Very low, multiplier = 0.75
Memory constraint	None, multiplier = 1
Tool use	Very high, multiplier = 0.72
Schedule	Normal, multiplier = 1
Adjusted COCOMO estimate	**295 person-months**

Project Duration

- COCOMO
  - $TDEV = 3 \times (PM)^{(0.33+0.2*(B-1.01))}$
- COCOMO 2
  - $TDEV = 3 \times (PM)^{(0.33+0.2*(B-1.01))} \times SCEDP/100$
  - TDEV – calendar months
  - PM – person effort computed by the COCOMO model
  - B – Exponent related to complexity
  - SCEDP - % increase or decrease in nominal schedule

COCOMO Example

System to be built

- An airline sales system is to be built in C:
  - Back-end database server has already been built.
- We will use **OP estimation** technique for high level estimates and **FP for detailed estimates**

COCOMO Example - Object Point Analysis

PM = (NOP x (1 - %reuse/100)) / PROD

- **PM** is the effort in person-months
- **NOP** is the number of object points
- **PROD** is the productivity

Object Point Analysis – Complexity Weighting

	Complexity		
Type of object	Simple	Medium	Difficult
Screen	1	2	3
Report	2	5	8
3GL component	N/A	N/A	10

Object Point Analysis - Screen

Number of views contained	Number and source of data tables		
	Total < 4 (<2 server, <2 client)	Total < 8 (2-3 server, 3-5 client)	Total 8+ (>3 server, >5 client)
< 3	Simple	Simple	Medium
3 – 7	Simple	Medium	Difficult
8+	Medium	Difficult	Difficult

Object Point Analysis - Reports

Number of sections contained	Number and source of data tables		
	Total < 4 (<2 server, <2 client)	Total < 8 (2-3 server, 3-5 client)	Total 8+ (>3 server, >5 client)
< 2	Simple	Simple	Medium
2 or 3	Simple	Medium	Difficult
> 3	Medium	Difficult	Difficult

Object Point Analysis – Productivity Rate

	Very low	Low	Nominal	High	Very High
Developer's experience and capability	4	7	13	25	50
CASE maturity and capability	4	7	13	25	50

Object Point Analysis

- Application will have 3 screens and will produce 1 report:
  - A booking screen: records **a new sale booking**
  - A pricing screen: shows the **rate** for each day and each flight
  - An availability screen: shows **available flights**
  - A sales report: shows **total sale figures** for the month and year, and compares figures with previous months and years

Rating of system

- Booking screen:
  - Needs 3 data tables (customer info, customer history table, available seats)
  - Only 1 view of the screen is enough. So, the booking screen is classified as simple.
- Similarly, the levels of difficulty of the pricing screen, the availability screen and the sales report are classified as simple, medium and medium, respectively. There is no 3GL component

Rating Results

Name	Objects	Complexity	Weight
Booking	Screen	Simple	1
Pricing	Screen	Simple	1
Availability	Screen	Medium	2
Sales	Report	Medium	5
		Total	9

- Assessment of the developers and the environment shows:
  - The developers' experience is very low (4)
  - The CASE tool is low (7). So, we have a productivity rate of 5.5
- The project requires approx. 1.64 (= 9/5.5) person-months

COCOMO Example - Function Point Analysis

Effort = $A \times (Size)^B \times M$

- A: 2.94
- Size: Estimated size in KLOC
- B: combined process factors
- M: combined effort factors

Function Point Table

Number of FPs	Complexity		
External user type	Low	Average	High
Inputs	3	4	6
Outputs	4	5	7
Files	7	10	15
Interfaces	5	7	10
Queries	3	4	6

Example of Function Point Analysis (FPA)

- An inventory system that needs to
  - ‘Add a record’
  - ‘Duplicate a record’,
  - ‘Calculate the total sum of multiple records’,
  - ‘Edit a record’, and
  - ‘Print a record’
  - will have
    - 3 inputs (add/duplicate/edit a record)
    - 1 output (print a record)
    - 1 query (calculation)

Function Point Estimation (FP->KLOC)

Name	External user types	Complexity	FP
Booking	External output type	Low	4
Pricing	External inquiry type	Low	3
Availability	External inquiry type	Medium	4
Sales	External output type	Medium	5
		Total	16

FP->LOC

- Total function points = 16
- Published figures for C show that:
  - 1 FP = 128 LOC in C
- Estimated Size
  - 16 * 128 = 2048 = 2 KLOC

Scale Factor Estimation (B)

Name	Very low (5)	Low (4)	Nominal (3)	High (2)	Very High (1)	Extra High (0)	**Assessment**	**Value**
Precedentedness	Thoroughly unprecedented	Largely unprecedented	Somewhat unprecedented	Generally familiar	Largely familiar	Thoroughly familiar	**Very high**	**1**
Flexibility	Rigorous	Occasional relaxation	Some relaxation	General conformity	Some conformity	General goals	**Very high**	**1**
Significant risks eliminated	Little (20%)	Some (40%)	Often (60%)	Generally (75%)	Mostly (90%)	Full (100%)	**Nominal**	**3**
Team interaction process	Very difficult	Some difficult	Basically cooperative	Largely cooperative	Highly cooperative	Seamless interactions	**High**	**2**
Process maturity	Level 1	Level 2	Level 2+	Level 3	Level 4	Level 5	**Low**	**4**
							Add	**1.01**
							Total	**1.12**

Effort Adjustment Factors (M)

Identifier	Name	Ranges (VL – EH)	Assessment VL/L/N/H/VH/EH	Values
RCPX	product Reliability and ComPleXity	0.5 – 1.5	low	0.75
RUSE	required reusability	0.5 – 1.5	nominal	1.0
PDIF	Platform DIFficulty	0.5 – 1.5	high	1.1
PERS	PERSonnel capability	1.5 – 0.5	high	0.75
PREX	PeRsonnel EXperience	1.5 – 0.5	very high	0.65
FCIL	FaCILities available	1.5 – 0.5	nomial	1.0
SCED	SChEDule pressure	1.5 – 0.5	low	1.2
			Product	0.4826

- Effort = $2.94 \times (2.048)^{1.12} \times 0.4826 = 3.80$ person-months

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