Global Institute of Technology, Jaipur
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Department of Computer Science & Engineering

Subject: SOFTWARE ENGINEERING

III Semester   Subject Code: 3CS4-07

SYLLABUS

UNIT 1: Introduction, software life-cycle models, software requirements specification, formal requirements specification, verification and validation.

UNIT 2: Software Project Management: Objectives, Resources and their estimation, LOC and FP estimation, effort estimation, COCOMO estimation model, risk analysis, software project scheduling.

UNIT 3: Requirement Analysis: Requirement analysis tasks, Analysis principles. Software prototyping and specification data dictionary, Finite State Machine (FSM) models. **Structured Analysis**: Data and control flow diagrams, control and process specification behavioral modeling

UNIT 4: Software Design: Design fundamentals, Effective modular design: Data architectural and procedural design, design documentation.

UNIT 5: Object Oriented Analysis: Object oriented Analysis Modeling, Data modeling. **Object Oriented Design**: OOD concepts, Class and object relationships, object modularization, Introduction to Unified Modeling Language

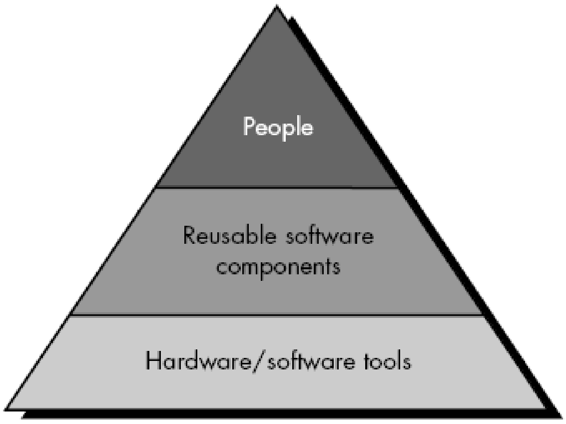
UNIT -2 SOFTWARE PROJECT MANAGEMENT

OBJECTIVES

The objective of software project planning is to provide a framework that enables the manager to make reasonable estimates of resources, cost, and schedule. These estimates are made within a limited time frame at the beginning of a software project and should be updated regularly as the project progresses. In addition, estimates should attempt to define best case and worst case scenarios so that project outcomes can be bounded. The planning objective is achieved through a process of information discovery that leads to reasonable estimates. In the following sections, each of the activities associated with software project planning is discussed.

RESOURCES

The second software planning task is estimation of the resources required to accomplish the software development effort. Figure illustrates development resources as a pyramid. The *development environment*—hardware and software tools—sits at the foundation of the resources pyramid and provides the infrastructure to support the development effort. At a higher level, we encounter reusable *software components*— software building blocks that can dramatically reduce development costs and accelerate delivery. At the top of the pyramid is the primary resource—*people.* Each resource is specified with four characteristics: description of the resource, a statement of availability, time when the resource will be required; duration of time that resource will be applied. The last two characteristics can be viewed as a time window.



Availability of the resource for a specified window must be established at the earliest practical time.

HUMAN RESOURCES

The planner begins by evaluating scope and selecting the skills required to complete development. Both organizational position (e.g., manager, senior software engineer) and specialty (e.g., telecommunications, database, client/server) are specified. For relatively small projects (one person-year or less), a single individual may perform all software engineering tasks, consulting with specialists as required. The number of people required for a software project can be determined only after an estimate of development effort (e.g., person-months) is made.

REUSABLE SOFTWARE RESOURCES

Component-based software engineering (CBSE)5 emphasizes reusability—that is, the creation and reuse of software building blocks [HOO91]. Such building blocks, often called *components*, must be cataloged for easy reference, standardized for easy application, and validated for easy integration.

Bennatan [BEN92] suggests four software resource categories that should be considered as planning proceeds:

Off-the-shelf components.

Existing software that can be acquired from a third party or that has been developed internally for a past project. COTS (commercial off-the-shelf) components are purchased from a third party, are ready for use on the current project, and have been fully validated.

Full-experience components.

Existing specifications, designs, code, or test data developed for past projects that are similar to the software to be built for the current project. Members of the current software team have had full experience in the application area represented by these components. Therefore, modifications required for full-experience components will be relatively low-risk.

Partial-experience components.

Existing specifications, designs, code, or test data developed for past projects that are related to the software to be built for the current project but will require substantial modification. Members of the current software team have only limited experience in the application area represented by these components. Therefore, modifications required for partial-experience components have a fair degree of risk.

New components.

Software components that must be built by the software team specifically for the needs of the current project. The following guidelines should be considered by the software planner when reusable components are specified as a resource.

DECOMPOSITION TECHNIQUES

Software Sizing

“Fuzzy logic” sizing. This approach uses the approximate reasoning techniques that are the cornerstone of fuzzy logic. To apply this approach, the planner must identify the type of application, establish its magnitude on a qualitative scale, and then refine the magnitude within the original range. Although personal experience can be used, the planner should also have access to a historical database of projects so that estimates can be compared to actual experience.

Function point sizing

Standard component sizing. For example, the standard components for an information system are subsystems, modules, screens, reports, interactive programs, batch programs, files, LOC, and object-level instructions. The project planner estimates the number of occurrences of each standard component and then uses historical project data to determine the delivered size per standard component. To illustrate, consider an information systems application. The planner estimates that 18 reports will be generated. Historical data indicates that 967 lines of COBOL are required per report. This enables the planner to estimate that 17,000 LOC will be required for the reports component. Similar estimates and computation are made for other standard components, and a combined size value (adjusted statistically) results.

Change sizing. This approach is used when a project encompasses the use of existing software that must be modified in some way as part of a project. The planner estimates the number and type (e.g., reuse, adding code, changing code, deleting code) of modifications that must be accomplished. Using an "effort ratio"for each type of change, the size of the change may be estimated

Problem-Based Estimation

LOC-Based Estimation

Function	Estimated LOC
User interface and control facilities (UICF)	2,300
Two-dimensional geometric analysis (2DGA)	5,300
Three-dimensional geometric analysis (3DGA)	6,800
Database management (DBM)	3,350
Computer graphics display facilities (CGDF)	4,950
Peripheral control function (PCF)	2,100
Design analysis modules (DAM)	8,400
Estimated lines of code	*33,200*

FP BASED ESTIMATION:

Information domain value	Opt.	Likely	Pess.	Est. count	Weight	FP count
Number of inputs	20	24	30	24	4	97
Number of outputs	12	15	22	16	5	78
Number of inquiries	16	22	28	22	5	88
Number of files	4	4	5	4	10	42
Number of external interfaces	2	2	3	2	7	15
Count total						*320*

Factor	Value
Backup and recovery	4
Data communications	2
Distributed processing	0
Performance critical	4
Existing operating environment	3
On-line data entry	4
Input transaction over multiple screens	5
Master files updated on-line	3
Information domain values complex	5
Internal processing complex	5
Code designed for reuse	4
Conversion/installation in design	3
Multiple installations	5
Application designed for change	5
Complexity adjustment factor	1.17

Finally, the estimated number of FP is derived:

$$FP_{\text{estimated}} = \text{count-total} \times [0.65 + 0.01 \times \Sigma\ (F_i)]$$

$$FP_{\text{estimated}} = 375$$

Process-Based Estimation

Activity →	CC	Planning	Risk analysis	Engineering		Construction release		CE	Totals
Task →				Analysis	Design	Code	Test		
Function ↓									
UICF				0.50	2.50	0.40	5.00	n/a	8.40
2DGA				0.75	4.00	0.60	2.00	n/a	7.35
3DGA				0.50	4.00	1.00	3.00	n/a	8.50
CGDF				0.50	3.00	1.00	1.50	n/a	6.00
DBM				0.50	3.00	0.75	1.50	n/a	5.75
PCF				0.25	2.00	0.50	1.50	n/a	4.25
DAM				0.50	2.00	0.50	2.00	n/a	5.00
Totals	0.25	0.25	0.25	3.50	20.50	4.50	16.50		46.00
% effort	1%	1%	1%	8%	45%	10%	36%		

CC = customer communication   CE = customer evaluation

Example: Compute the function point, productivity, documentation, cost per function for the following data:

1. Number of user inputs = 24
2. Number of user outputs = 46
3. Number of inquiries = 8
4. Number of files = 4
5. Number of external interfaces = 2
6. Effort = 36.9 p-m
7. Technical documents = 265 pages
8. User documents = 122 pages
9. Cost = $7744/ month

Various processing complexity factors are: 4, 1, 0, 3, 3, 5, 4, 4, 3, 3, 2, 2, 4, 5.

Solution:

Measurement Parameter	Count		Weighing factor
1. Number of external inputs (EI)	24	*	4 = 96
2. Number of external outputs (EO)	46	*	4 = 184

3. Number of external inquiries (EQ)	8	*	6 = 48
4. Number of internal files (ILF)	4	*	10 = 40
5. Number of external interfaces (EIF) Count-total →	2	*	5 = 10 378

So sum of all f_i (i ← 1 to 14) = 4 + 1 + 0 + 3 + 5 + 4 + 4 + 3 + 3 + 2 + 2 + 4 + 5 = 43

FP = Count-total * [0.65 + 0.01 *$\Sigma(f_i)$]
= 378 * [0.65 + 0.01 * 43]
= 378 * [0.65 + 0.43]
= 378 * 1.08 = 408

$$\text{Productivity} = \frac{\text{FP}}{\text{Effort}} = \frac{408}{36.9} = 11.1$$

Total pages of documentation = technical document + user document
= 265 + 122 = 387pages

Documentation = Pages of documentation/FP
= 387/408 = 0.94

$$\text{Cost per function} = \frac{\text{cost}}{\text{productivity}} = \frac{7744}{11.1} = \$700$$

Differentiate between FP and LOC

FP	LOC
1. FP is specification based.	1. LOC is an analogy based.
2. FP is language independent.	2. LOC is language dependent.
3. FP is user-oriented.	3. LOC is design-oriented.
4. It is extendible to LOC.	4. It is convertible to FP (backfiring)

PROJECT PLANNING OBJECTIVES

The objective of software project planning is to provide a framework that enables the manager to make reasonable estimates of resources, cost, and schedule. These estimates are made within a limited time frame at the beginning of a software project and should be updated regularly as the project progresses. In addition, estimates should attempt to define best case and worst case scenarios so that project outcomes can be bounded.

The planning objective is achieved through a process of information discovery that leads to reasonable estimates. In the following sections, each of the activities associated with software project planning is discussed.

THE COCOMO MODEL

COCOMO (Constructive Cost Model) is a regression model based on LOC, i.e **number of Lines of Code**. It is a procedural cost estimate model for software projects and often used as a process of reliably predicting the various parameters associated with making a project such as size, effort, cost, time and quality. It was proposed by Barry Boehm in 1970 and is based on the study of 63 projects, which make it one of the best-documented models.

The key parameters which define the quality of any software products, which are also an outcome of the COCOMO are primarily Effort & Schedule:

- **Effort:** Amount of labor that will be required to complete a task. It is measured in person-months units.
- **Schedule:** Simply means the amount of time required for the completion of the job, which is, of course, proportional to the effort put. It is measured in the units of time such as weeks, months.

Different models of COCOMO have been proposed to predict the cost estimation at different levels, based on the amount of accuracy and correctness required. All of these models can be applied to a variety of projects, whose characteristics determine the value of constant to be used in subsequent calculations. These characteristics pertaining to different system types are mentioned below.

Boehm's definition of organic, semidetached, and embedded systems:

1. **Organic –** A software project is said to be an organic type if the team size required is adequately small, the problem is well understood and has been solved in the past and also the team members have a nominal experience regarding the problem.
2. **Semi-detached –** A software project is said to be a Semi-detached type if the vital characteristics such as team-size, experience, knowledge of the various programming environment lie in between that of organic and Embedded. The projects classified as Semi-Detached are comparatively less familiar and difficult to develop compared to the organic ones and require more experience and better guidance and creativity. Eg: Compilers or different Embedded Systems can be considered of Semi-Detached type.
3. **Embedded –** A software project with requiring the highest level of complexity, creativity, and experience requirement fall under this category. Such software requires a larger team size than the other two models and also the developers need to be sufficiently experienced and creative to develop such complex models.

All the above system types utilize different values of the constants used in Effort Calculations.

Types of Models: COCOMO consists of a hierarchy of three increasingly detailed and accurate forms. Any of the three forms can be adopted according to our requirements. These are types of COCOMO model:

1. Basic COCOMO Model
2. Intermediate COCOMO Model
3. Detailed COCOMO Model

The first level, **Basic COCOMO** can be used for quick and slightly rough calculations of Software Costs. Its accuracy is somewhat restricted due to the absence of sufficient factor considerations.

Intermediate COCOMO takes these Cost Drivers into account and **Detailed COCOMO** additionally accounts for the influence of individual project phases, i.e in case of Detailed it accounts for both these cost drivers and also calculations are performed phase wise henceforth producing a more accurate result. These two models are further discussed below.

Estimation of Effort: Calculations –

1. Basic Model –

$$\mathrm{E} = \mathrm{a}(\mathrm{KLOC})^b$$

$$time = c(Effort)^d$$

$$Personrequired = Effort/time$$

The above formula is used for the cost estimation of for the basic COCOMO model, and also is used in the subsequent models. The constant values a,b,c and d for the Basic Model for the different categories of system:

SOFTWARE PROJECTS	a	b	c	d
Organic	2.4	1.05	2.5	0.38
Semi Detached	3.0	1.12	2.5	0.35
Embedded	3.6	1.20	2.5	0.32

The effort is measured in Person-Months and as evident from the formula is dependent on Kilo-Lines of code.

The development time is measured in Months.

These formulas are used as such in the Basic Model calculations, as not much consideration of different factors such as reliability, expertise is taken into account, henceforth the estimate is rough.

2. Intermediate Model –

The basic Cocomo model assumes that the effort is only a function of the number of lines of code and some constants evaluated according to the different software system. However, in reality, no system's effort and schedule can be solely calculated on the basis of Lines of Code. For that, various other factors such as reliability, experience, Capability. These factors are known as Cost Drivers and the Intermediate Model utilizes 15 such drivers for cost estimation.

Classification of Cost Drivers and their attributes:

(i) Product attributes –

- Required software reliability extent
- Size of the application database
- The complexity of the product

(ii) Hardware attributes –

- Run-time performance constraints
- Memory constraints
- The volatility of the virtual machine environment
- Required turnabout time

(iii) Personnel attributes –

- Analyst capability
- Software engineering capability
- Applications experience
- Virtual machine experience
- Programming language experience

(iv) Project attributes –

- Use of software tools

- Application of software engineering methods
- Required development schedule

COST DRIVERS	VERY LOW	LOW	NOMINAL	HIGH	VERY HIGH
1. Product Attributes					
Required Software Reliability	0.75	0.88	1.00	1.15	1.40
Size of Application Database		0.94	1.00	1.08	1.16
Complexity of The Product	0.70	0.85	1.00	1.15	1.30
2. Hardware Attributes					
Runtime Performance Constraints			1.00	1.11	1.30
Memory Constraints			1.00	1.06	1.21
Volatility of the virtual machine environment		0.87	1.00	1.15	1.30
Required turnabout time		0.94	1.00	1.07	1.15
3. Personnel attributes					
Analyst capability	1.46	1.19	1.00	0.86	0.71
Applications experience	1.29	1.13	1.00	0.91	0.82
Software engineer capability	1.42	1.17	1.00	0.86	0.70

Virtual machine experience	1.21	1.10	1.00	0.90	
Programming language experience	1.14	1.07	1.00	0.95	
4. Project Attributes					
Application of software engineering methods	1.24	1.10	1.00	0.91	0.82
Use of software tools	1.24	1.10	1.00	0.91	0.83
Required development schedule	1.23	1.08	1.00	1.04	1.10

The project manager is to rate these 15 different parameters for a particular project on a scale of one to three. Then, depending on these ratings, appropriate cost driver values are taken from the above table. These 15 values are then multiplied to calculate the EAF (Effort Adjustment Factor). The Intermediate COCOMO formula now takes the form:

$$\mathrm{E}= (\mathrm{a}(\mathrm{KLOC})^{b}) * EAF$$

The values of a and b in case of the intermediate model are as follows:

SOFTWARE PROJECTS	a	b
Organic	3.2	1.05
Semi Detached	3.0	1.12
Embeddedc	2.8	1.20

2. **Detailed Model –**
Detailed COCOMO incorporates all characteristics of the intermediate version with an assessment of the cost driver's impact on each step of the software engineering process. The detailed model uses different effort multipliers for each cost driver

attribute. In detailed cocomo, the whole software is divided into different modules and then we apply COCOMO in different modules to estimate effort and then sum the effort. The Six phases of detailed COCOMO are:

1. Planning and requirements
2. System design
3. Detailed design
4. Module code and test
5. Integration and test
6. Cost Constructive model

The effort is calculated as a function of program size and a set of cost drivers are given according to each phase of the software lifecycle.

RISK ANALYSIS

First, risk concerns future happenings. Today and yesterday are beyond active concern, as we are already reaping what was previously sowed by our past actions. The question is, can we, therefore, by changing our actions today, create an opportunity for a different and hopefully better situation for ourselves tomorrow. This means second, that risk involves change, such as in changes of mind, opinion, actions, or places . . . [Third,] risk involves choice, and the uncertainty that choice itself entails.

What is it?

Risk analysis and management are a series of steps that help a software team to understand and manage uncertainty. Many problems can plague a software project. A risk is a potential problem—it might happen, it might not. But, regardless of the outcome, it's a really good idea to identify it, assess its probability of occurrence, estimate its impact, and establish a contingency plan should the problem actually occur.

Who does it?

Everyone involved in the software process—managers, software engineers, and customers participate in risk analysis and management.

SOFTWARE RISKS

There is general agreement that risk always involves two characteristics

• *Uncertainty*—the risk may or may not happen; that is, there are no 100% probable risks.

• *Loss*—if the risk becomes a reality, unwanted consequences or losses will occur.

When risks are analyzed, it is important to quantify the level of uncertainty and the degree of loss associated with each risk. To accomplish this, different categories of risks are considered.

Project risks threaten the project plan. That is, if project risks become real, it is likely that project schedule will slip and that costs will increase. Project risks identify potential budgetary, schedule, personnel (staffing and organization), resource, customer, and requirements problems and their impact on a software project. project complexity, size, and the degree of structural uncertainty were also defined as project (and estimation) risk factors.

Technical risks threaten the quality and timeliness of the software to be produced. If a technical risk becomes a reality, implementation may become difficult or impossible. Technical risks identify potential design, implementation, interface, verification, and maintenance problems. In addition, specification ambiguity, technical uncertainty, technical obsolescence, and "leading-edge" technology are also risk factors. Technical risks occur because the problem is harder to solve than we thought it would be.

Business risks threaten the viability of the software to be built. Business risks often jeopardize the project or the product. Candidates for the top five business risks are

(1) building a excellent product or system that no one really wants (market risk),

(2)building a product that no longer fits into the overall business strategy for the company (strategic risk)

(3) building a product that the sales persons doesn't understand how to sell

(4) losing the support of senior management due to a change in focus or a change in people (management risk)

(5) losing budgetary or personnel commitment (budget risks).

It is extremely important to note that simple categorization won't always work. Some risks are simply unpredictable in advance.

Another general categorization of risks has been proposed by Charette [CHA89]. *Known risks* are those that can be uncovered after careful evaluation of the project plan, the business and technical environment in which the project is being developed, and other reliable information sources (e.g., unrealistic delivery date, lack of documented requirements or software scope, poor development environment).

Predictable risks are extrapolated from past project experience (e.g., staff turnover, poor communication with the customer, dilution of staff effort as ongoing maintenance requests are serviced).

Unpredictable risks are the joker in the deck. They can and do occur, but they are extremely difficult to identify in advance.

RISK IDENTIFICATION

Risk identification is a systematic attempt to specify threats to the project plan (estimates, schedule, resource loading, etc.). By identifying known and predictable risks, the project manager takes a first step toward avoiding them when possible and controlling them when necessary.

There are two distinct types of risks for each of the categories that have been presented earlier : generic risks and product-specific risks.

Generic risks are a potential threat to every software project.

Product-specific risks can be identified only by those with a clear understanding of the technology, the people, and the environment that is specific to the project at hand. To identify product-specific risks, the project plan and the software statement of scope are examined and an answer to the following question is developed: "What special characteristics of this product may threaten our project plan?"

One method for identifying risks is to create a *risk item checklist.* The checklist can be used for risk identification and focuses on some subset of known and predictable risks in the following generic subcategories:

• *Product size*—risks associated with the overall size of the software to be built or modified.

• *Business impact*—risks associated with constraints imposed by management or the marketplace.

• *Customer characteristics*—risks associated with the sophistication of the customer and the developer's ability to communicate with the customer in a timely manner.

• *Process definition*—risks associated with the degree to which the software process has been defined and is followed by the development organization.

• *Development environment*—risks associated with the availability and quality of the tools to be used to build the product.

• *Technology to be built*—risks associated with the complexity of the system to be built and the "newness" of the technology that is packaged by the system.

• *Staff size and experience*—risks associated with the overall technical and project experience of the software engineers who will do the work.

The risk item checklist can be organized in different ways. Questions relevant to each of the topics can be answered for each software project. The answers to these questions allow the planner to estimate the impact of risk. A different risk item checklist format simply lists characteristics that are relevant to each generic subcategory. Finally, a set of “risk components and drivers" [AFC88] are listed along with their probability *Although generic risks are important to consider, usually the product-specific risks cause the most headaches. Be certain to spend the time to identify as many product-specific risks as possible.*

RISK COMPONENT & DRIVERS

The risk components are defined in the following manner:

• *Performance risk*—the degree of uncertainty that the product will meet its requirements and be fit for its intended use.

• *Cost risk*—the degree of uncertainty that the project budget will be maintained.

• *Support risk*—the degree of uncertainty that the resultant software will be easy to correct, adapt, and enhance.

• *Schedule risk*—the degree of uncertainty that the project schedule will be maintained and that the product will be delivered on time.

Category \ Components		Performance	Support	Cost	Schedule
Catastrophic	1	Failure to meet the requirement would result in mission failure		Failure results in increased costs and schedule delays with expected values in excess of $500K	
	2	Significant degradation to nonachievement of technical performance	Nonresponsive or unsupportable software	Significant financial shortages, budget overrun likely	Unachievable IOC
Critical	1	Failure to meet the requirement would degrade system performance to a point where mission success is questionable		Failure results in operational delays and/or increased costs with expected value of $100K to $500K	
	2	Some reduction in technical performance	Minor delays in software modifications	Some shortage of financial resources, possible overruns	Possible slippage in IOC
Marginal	1	Failure to meet the requirement would result in degradation of secondary mission		Costs, impacts, and/or recoverable schedule slips with expected value of $1K to $100K	
	2	Minimal to small reduction in technical performance	Responsive software support	Sufficient financial resources	Realistic, achievable schedule
Negligible	1	Failure to meet the requirement would create inconvenience or nonoperational impact		Error results in minor cost and/or schedule impact with expected value of less than $1K	
	2	No reduction in technical performance	Easily supportable software	Possible budget underrun	Early achievable IOC

RISK MITIGATION, MONITORING, AND MANAGEMENT

All of the risk analysis activities presented to this point have a single goal—to assist the project team in developing a strategy for dealing with risk. An effective strategy must consider three issues:

• risk avoidance

• risk monitoring

• risk management and contingency planning

SOFTWARE PROJECT SCHEDULING

Software project scheduling is an activity that distributes estimated effort across the planned project duration by allocating the effort to specific software engineering tasks. During early stages of project planning, a *macroscopic schedule* is developed. This type of schedule identifies all major software engineering activities and the product functions to which they are applied. As the project gets under way, each entry on the macroscopic schedule is refined into a *detailed schedule*. Here, specific software tasks (required to accomplish an activity) are identified and scheduled. Scheduling for software engineering projects can be viewed from two rather different perspectives. In the first, an end-date for release of a computer-based system has already (and irrevocably) been established. The software organization is constrained to distribute effort within the prescribed time frame. The second view of software scheduling assumes that rough chronological bounds have been discussed but that the end-date is set by the software engineering organization. Effort is distributed to make best use of resources and an end-date is defined after careful analysis of the software. Unfortunately, the first situation is encountered far more frequently than the second. Like all other areas of software engineering, a number of basic principles guide

software project scheduling:

Compartmentalization. The project must be compartmentalized into a number of manageable activities and tasks. To accomplish compartmentalization, both the product and the process are decomposed .

Interdependency. The interdependency of each compartmentalized activity or task must be determined. Some tasks must occur in sequence while others can occur in parallel. Some activities cannot commence until the work product produced by another is available. Other activities can occur independently.

Time allocation. Each task to be scheduled must be allocated some number of work units (e.g., person-days of effort). In addition, each task must be assigned a start date and a completion date that are a function of the interdependencies and whether work will be conducted on a full-time or part-time basis.

Effort validation. Every project has a defined number of staff members. As time allocation occurs, the project manager must ensure that no more than the allocated number of people have been scheduled at any given time. For example, consider a project that has three assigned staff members (e.g., 3 person-days are available per day of assigned effort5). On a given day, seven concurrent tasks must be accomplished. Each task requires 0.50 person days of effort. More effort has been allocated than there are people to do the work.

Defined responsibilities. Every task that is scheduled should be assigned to a specific team member.

Defined outcomes. Every task that is scheduled should have a defined outcome. For software projects, the outcome is normally a work product (e.g. the design of a module) or a part of a work product. Work products are often combined in deliverables.

Defined milestones. Every task or group of tasks should be associated with a project milestone. A milestone is accomplished when one or more work products has been reviewed for quality and has been approved.

Each of these principles is applied as the project schedule evolves.

SCHEDULING

Scheduling of a software project does not differ greatly from scheduling of any multitask engineering effort. Therefore, generalized project scheduling tools and techniques can be applied with little modification to software projects.

Program evaluation and review technique (PERT) and ***critical path method*** (CPM)

[MOD83] are two project scheduling methods that can be applied to software development. Both techniques are driven by information already developed in earlier project planning activities:

• Estimates of effort

• A decomposition of the product function

• The selection of the appropriate process model and task set

• Decomposition of tasks

Interdependencies among tasks may be defined using a task network. Tasks, sometimes called the project *work breakdown structure* (WBS), are defined for the product as a whole or for individual functions.

Both PERT and CPM provide quantitative tools that allow the software planner to

(1) determine the *critical path*—the chain of tasks that determines the duration of the project;

(2) establish "most likely" time estimates for individual tasks by applying statistical models;

(3) calculate "boundary times" that define a time "window" for a particular task.

Boundary time calculations can be very useful in software project scheduling. Slippage in the design of one function, for example, can retard further development of other functions.

Riggs describes important boundary times that may be discerned from a PERT or CPM network:

(1) the earliest time that a task can begin when all preceding tasks are completed in the shortest possible time,

(2) the latest time for task initiation before the minimum project completion time is delayed,

(3) the earliest finish—the sum of the earliest start and the task duration,

(4) the latest finish the latest start time added to task duration, and

(5) the *total float*—the amount of surplus time or leeway allowed in scheduling tasks so that the network critical path is maintained on schedule. Boundary time calculations lead to a determination of critical path and provide the manager with a quantitative method for evaluating progress as tasks are completed.