Chapter 2
The Foundations of Project Management

Project management, in some form, has existed for thousands of years. Some notable examples are the great pyramids, Moses' movement of the Israelites out of Egypt, the temple and palace built by Solomon, and the magnificent building programs of the Greeks and the Romans. How these projects were accomplished at all defies imagination, particularly given the tools of the day. For instance, how was the Great Pyramid of Cheops, consisting of an estimated 2,300,000 stone blocks, weighing two to seventy tons each, built with such precision? This pyramid, the size of a forty-story building, stands on a thirteen-acre base that even today deviates less than an inch off level.

With the advent of electricity and industrialization, project complexity increased. No longer were projects complex principally because they were large-scale exercises in endurance. Now they were complex because of their scale. In addition, because of component complexity, they demanded improved project management techniques and tools. The catalyst for these improvements was World War II and the resulting cold war.

World War II brought a refinement to project management that had never been experienced. Manufacturing and production lines were optimized for producing war materials faster and better.

Management of these efforts required new and better project management techniques, resulting in a surge of new thinking in project management. The United States Department of Defense (DOD) began to develop or contract for new and better tools and techniques for managing projects. Projects such as the Polaris submarine involved so many contractors and so much development that it was virtually impossible to schedule or track progress using standard management techniques. Thus, scheduling and network analysis techniques were developed to provide consistent project tracking and controlling techniques. Consequently, the DOD is directly responsible for introducing nearly all the traditional project management tools used by professional project managers today.

IT projects have created more project management challenges. To exacerbate the challenge of project complexity, nearly all IT projects have the added constraint of tighter schedules, usually imposed by the need to rush to market.

IT is pervasive. The technological fuel for this pervasiveness is not just the computer. It is the marriage of computer technology with communication technology. The explosion of IT onto the world has solved many business problems and opened new business directions, but it has also created some serious management issues.

IT Benefits and Issues

One of the major benefits of IT is that companies now have the ability to communicate rapidly across organizational, national, and international lines, making it the backbone of virtually every business today. With this newfound capability, every company has the opportunity to make their management processes more effective and efficient. Unfortunately, many businesses do not have the expertise or cultural inclination to make the changes required. It is a major challenge to adapt management and support processes to keep pace with IT changes.

The track record for managing IT projects is not good, and the principal reason is the lack of project planning brought on by the need to rush to market, which creates the perception of limited or no planning time. Another reason is the lack of organizational commitment to becoming a project-oriented organization, which requires, among other things, a formal and documented management process, a specially selected and trained project management cadre, and the understanding and use of standard project management tools. Project management processes and project manager selection and characteristics are discussed in the next chapter.

Fundamental Definitions in a Project-Oriented Environment

To ensure a common understanding of project management tools, this chapter will define some basic project-oriented terms and will discuss four of project management's most important tools: the work breakdown structure (WBS), the Gantt chart, network diagramming, and earned value. These important tools are the foundations of project management regardless of the type project.

Project and Project Management

A project is usually a onetime activity with a well-defined set of desired end results. It is this onetime characteristic that differentiates project activities from functional activities. For example, individuals in a functional department, such as human resources, may have specific projects assigned to them, but their usual responsibilities are recurring. A project is defined as a unique, temporary effort to produce specific deliverables measured against customer-specified performance criteria.

Project Uniqueness

Every project is unique. No two projects are alike, regardless of how routine they are to the organization. Each one is characterized by some degree of customization. Even if two projects were exactly alike technically, differences would be noticeable because the four parties at interest, or stakeholders (i.e., client or customer, parent organization, project team, and the public), define success or failure in different ways. In addition, the stakeholder group is usually different for each project.

Temporary Duration

In the context of project duration, the term "temporary" is dependent on the industry or one's perception of time. For example, in the construction industry, a house might be built in six months, while a hospital might take two years to build. In the aerospace industry, a new aircraft development effort can take ten or more years. So temporary doesn't mean short-term as we generally use it, but rather it means that there are definite beginning and end points to the effort.

Customer-Specified Performance Criteria

The customer, whether internal or external, defines the level of performance required for the project deliverables. The customer or client defines these performance criteria in terms of requirements. It is the responsibility of the project manager to interpret the requirements and to obtain agreement from the customer that the interpretation accurately reflects the customer's needs. It is also the responsibility of the project manager to identify or develop standards against which to measure whether these requirements are met.

In some instances, industry standards can be used to measure performance criteria. For example, electrical codes exist for those projects requiring electrical wiring or power connections. Sometimes standards are a part of the performance criteria. For instance, a requirement of mean-time-between-failure (MTBF) of some number of hours can also serve as a standard. This is because MTBF is a quantifiable measure and can be identified with average acceptable values for similar systems. When standards are not available, the project manager is responsible for providing a way to determine whether the product is acceptable to the customer. One way might be to use an independent quality assurance group. Another way might be to write a standard or to use another company's product as a benchmark. The key to success in identifying, interpreting, and measuring customer requirements is to obtain customer input and agreement about your interpretation of these requirements and about how your performance will be measured.

Project Management Defined

Project management is a specialized approach to managing business. The traditional view of management is that we plan, organize, lead, and control the business process. Project management includes these functions but also includes project initiation and termination. Both traditional and project management processes are shown graphically in Exhibits 2-1 and 2-2, respectively. We can define project management as the art and science of managing projects to a specific schedule, at or below a predetermined budget, to the customer's performance requirements and within the resources available.

Project management is both an art and a science. It is an art because it involves strong interrelationships with diverse groups. This part of project management is actually what makes it so challenging. Generally, the bigger project problems are those associated with the human element: conflict resolution, team building, and negotiating. Technical problems are far easier to solve than human problems. These technical tools make project management partly a science.

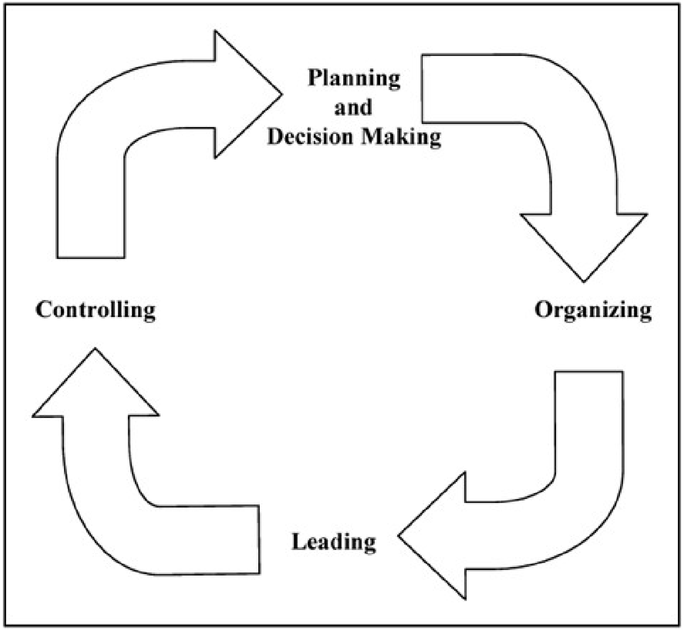

Exhibit 2-1. Traditional management functions.

There are many project management tools. Some are simple one-page forms. Others involve relatively complex calculations. Many of these tools are presented in this book, but the four most important ones are the WBS, the Gantt chart, network analysis, and earned value.

The Work Breakdown Structure

WBS is the most important project management tool. With a good WBS, the project manager can develop every other tool needed to successfully manage the project. When done correctly, it is the basis for planning, scheduling, budgeting, and controlling the project.

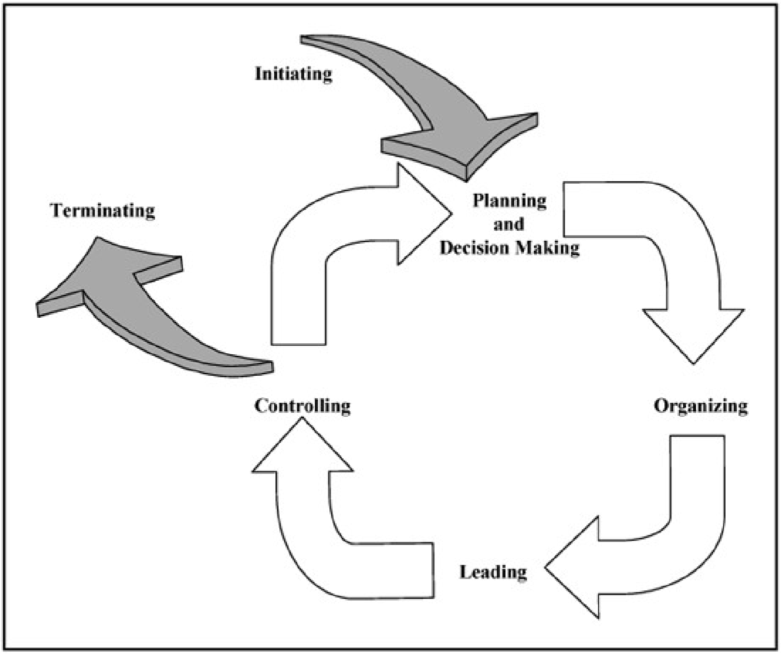

Exhibit 2-2. Project management functions.

What Is a Work Breakdown Structure?

A WBS is a structured way of decomposing a project into its various components—software, hardware, communications network, services, documentation, labor, testing, implementation, installation, and maintenance. In short, WBS is a formalized way of reducing the project into successively lower levels of greater detail.

There are two ways to represent a WBS. The first and most popular form is called the indented format. The indented format derives its name from the practice of indenting each successively lower level, as shown in Exhibit 2-3.

The graphical format, shown in Exhibit 2-4, resembles an organizational chart and is especially helpful for those who prefer visual representations. However, it requires a lot of space to de-

WBS Number	Description	WBS Level
1.0	Project or Contract Name	1
1.1	Major Project Subdivision	2
1.1.1	Task	3
1.1.1.1	Subtask	4
1.1.1.1.1	Work Package	5
1.1.1.1.1.1	Components	6

Exhibit 2-3. Indented WBS.

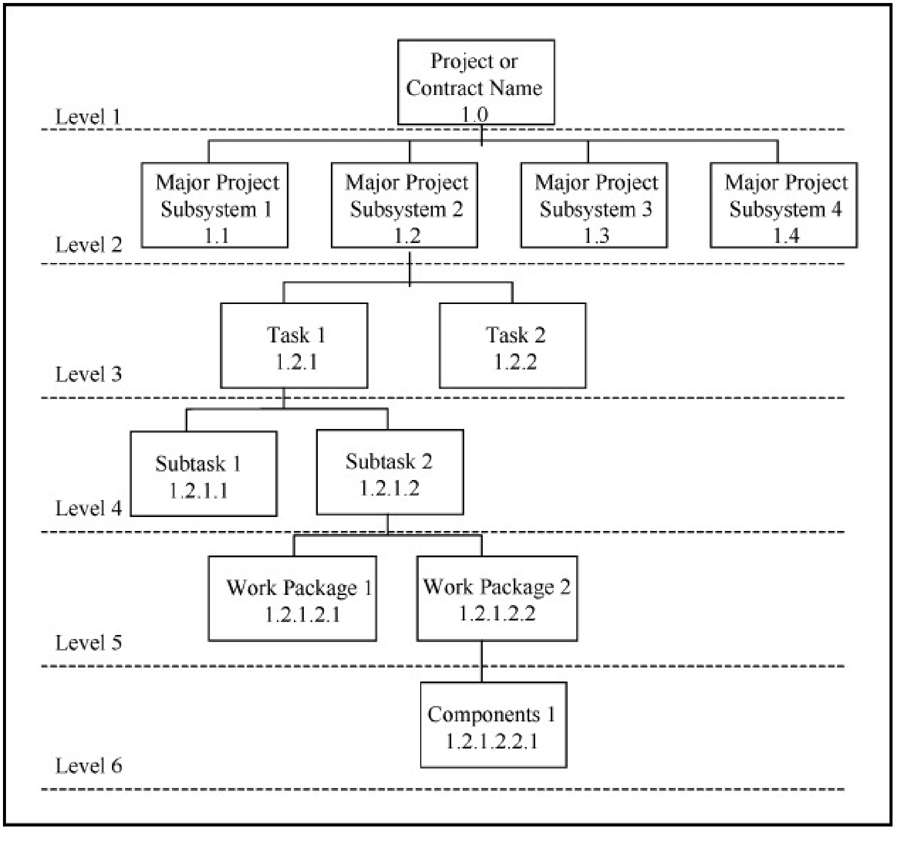

Exhibit 2-4. Graphical WBS format.

velop, particularly for large, complex projects. Not all project management software supports the graphical format, but all of them support the indented representation.

The WBS Levels

WBS levels refer to the successively lower tiers of detail beginning with the project name as the first level. Usually, a WBS is developed to the third or fourth level but rarely needs to be developed below the fifth level. There are two key points in WBS development. First, the level of development has nothing to do with the type of project, the industry, or the customer—private or public. It has to do with the complexity of the project. A WBS to the third level can easily describe a simple project of a few tasks. But a project such as building a house, hospital, or airplane requires a detailed WBS to at least the fifth level.

The WBS Levels Described

Each of the WBS levels are described as follows:

- ✔ ***Level One.*** The project or contract name is always at this level.
- ✔ ***Level Two.*** Entries involving the major subsystems of the project, complete entities, or sections of the project are at this level. For example, the major subsystems of an automobile design project would include the engine, chassis, interior, and body.
- ✔ ***Level Three.*** Each level two entry also can consist of one or more major task activities. For example, if the level two subsystem is the engine, tasks might be the fan or carburetor, which are parts of the engine. These are designated as level three activities.
- ✔ ***Level Four.*** Each level three activity can be decomposed into several more discrete entities, and so on, until the desired level

of detail is achieved. For example, a subtask of the carburetor would be to design and build fuel jets. These level three sub-tasks are all entered into the WBS at level four.

- ***Level Five.*** Decomposing level four tasks usually brings us to a level where the actual work can be assigned: the work package. The work package is identifiable with a person, a job, or a budget number and is where the actual project work is accomplished. The work package can occur anywhere below the first level, but usually occurs at the fourth or fifth level. The idea is to define the work package at a level where the project manager is comfortable that he can manage the work.

  An example of a fifth-level work package is the subtask of defining a valve for the fuel jets described at level four. This is a discrete work package, which can be given to an individual or group. Now a schedule and budget for the effort can be assigned.

A sample WBS is presented in Exhibit 2-5. Several key points about this example should be noted. First, the name of the project is at the first level. Second, not every major subsystem or subproject is decomposed to the same level. It is only necessary to decompose the elements of the WBS to the level at which it is possible to assign individuals, a budget, and a schedule to the task. Each project manager will have a different view of the required level of WBS decomposition. My level of comfort, relative to managing the project, might require that I decompose all the WBS elements to the fourth level, while you may be comfortable operating at the third level. The third thing to note about the sample WBS is that the lowest levels—that is, work packages—are described by a verb, while nouns describe higher levels. This rule of thumb is helpful in developing a WBS—when the element can be introduced by a verb; for example, develop, build, write, document. Then it probably is a work package and need not be decomposed to a lower level.

Note in Exhibit 2-5 that I included the project management

1.0 Management Information Software System

- 1.1. Gap Analysis
  - 1.1.1. Needs assessment
    - 1.1.1.1. Measure state of current system.
    - 1.1.1.2. Determine additional capability requirements.
  - 1.1.2. Develop alternative approaches.
- 1.2. Requirements Specifications
  - 1.2.1. Develop preliminary software specifications.
  - 1.2.2. Develop detailed software specifications.
  - 1.2.3. Develop preliminary hardware specifications.
- 1.3. Systems Engineering
  - 1.3.1. Develop alternative software approaches.
  - 1.3.2. Develop alternative hardware approaches.
  - 1.3.3. Develop cost estimates for each alternative approach.
  - 1.3.4. Determine best technical and most cost-effective approach.
  - 1.3.5. Develop preferred system architecture.
- 1.4. System Design
  - 1.4.1. Develop preliminary system design.
    - 1.4.1.1. Design software modules.
    - 1.4.1.2. Design hardware subsystems.
    - 1.4.1.3. Integrate systems.
    - 1.4.1.4. Develop detailed system design.
- 1.5. System Development
  - 1.5.1. Write code for system modules.
  - 1.5.2. Construct hardware subsystems.
  - 1.5.3. Develop prototype.
- 1.6. Testing
  - 1.6.1. Write test plans.
  - 1.6.2. Test units.
    - 1.6.2.1. Test code.
    - 1.6.2.2. Modify code.
    - 1.6.2.3. Test hardware.
    - 1.6.2.4. Modify hardware.
  - 1.6.3. System testing.
    - 1.6.3.1. Integrate system.
    - 1.6.3.2. Test code.
    - 1.6.3.3. Modify code.
    - 1.6.3.4. Test hardware.
    - 1.6.3.5. Modify hardware.
  - 1.6.4. Prototype tests.
    - 1.6.4.1. Conduct prototype tests.
    - 1.6.4.2. Document test results.
    - 1.6.4.3. Modify module code/hardware.
- 1.7. Develop Production Model
  - 1.7.1. Develop production tests.
    - 1.7.1.1. Conduct tests.
    - 1.7.1.2. Document test results.
  - 1.7.2. Conduct deployment.
    - 1.7.2.1. Deliver system.
    - 1.7.2.2. Install system.
  - 1.7.3. Maintain system.
    - 1.7.3.1. Detect/correct faults.
    - 1.7.3.2. Modify/enhance system.
- 1.8. Project Management
  - 1.8.1. Assign project manager.
  - 1.8.2. Assign project engineer.
  - 1.8.3. Assign administrative assistant.
  - 1.8.4. Assign cost analyst.

Exhibit 2-5. Sample work breakdown structure.

functions as a line item entry. Although these functions are not tasks in the context of usual WBS elements, listing them is a good way to collect costs associated with the project management activity. Otherwise, the cost of project management time must be spread across each task in the project, a formidable effort. Therefore, rather than apportioning the project manager's time to every single task, it is much easier to include a separate WBS entry and provide one total cost for the estimated project duration.

The primary objective in developing a WBS is to ensure that every project task is identified. It is not an objective to determine or record the interdependencies of the tasks at this point. In fact, it is better not to think in terms of task dependencies until all tasks are identified. Concentrate on identifying all the tasks first, because if it is not in the WBS, it is not in the project. The network is the tool used to show task relationships.

Network Analysis

Networks have been used since the early 1950s, when Lockheed and Booz Allen Hamilton developed the project evaluation review technique (PERT) for the Navy's Polaris missile program. Since then, several other network techniques have been developed to compensate for some shortcomings in the PERT method and to provide additional capabilities. Although the PERT network method is still used occasionally, the most common network analysis technique is the precedence diagram method (PDM). This technique eliminates some of the problems with PERT, but it owes its popularity to Microsoft Project and other project management software because it is easier to program. Since PDM is the generally preferred and used network tool, only its development and analysis is shown in this chapter. However, the PERT technique will be discussed in Chapter 6 as a risk mitigation tool. You can find more detailed discussions of PERT and other networking techniques in most basic project management texts.

The first step in developing the project schedule is to estimate the duration of each individual task. Duration estimation should include any contingencies to plan against potential resource shortages. That is, the best-case scenario should not be assumed for the duration—neither should the worst-case scenario. The duration is usually taken to be the average of similar tasks from the organization's historical database. But those tasks at risk, relative to potentially unavailable resource numbers or skills, should be planned with a contingency factor. One of the major benefits of the PDM method is that it can accommodate and track this kind of planning, whereas the PERT method cannot.

Task leaders typically estimate duration and labor requirements, but some organizations prefer that the functional managers make those estimates, since they are the ones who allocate resources and better understand project priorities. Once all task durations are estimated, the next step is to determine task interdependencies.

Determining task interdependencies is a team effort because each task leader will better understand what she needs as output from other tasks before she can finish her own effort. Task interdependencies drive the schedule because some tasks simply cannot begin until other tasks are completed. For example, the task of system design must be completed before system construction begins. On the other hand, some tasks have no dependencies and can be accomplished in parallel with other tasks. The testing of a completed subsystem, for example, can be accomplished while another subsystem is in development. So careful examination of task interdependencies can shorten the schedule, if two or more tasks are done at the same time rather than sequentially. However, doing this may add substantial risk to the project, which is the trade-off against potential schedule improvement.

For example, you may have planned a technology survey before designing a critical subsystem, but you may then decide to begin the design and survey at the same time in order to use the survey results to validate your understanding of the state of the available technology. If your knowledge of the available technology is current, this approach is viable and could improve the schedule significantly. However, if the survey comes back indicating that your choice of system components is obsolete, then not only have you not improved the schedule, but very likely you have created a schedule slip. Considering each task in turn, and its relationship to every other project task, results in a precedence table, as shown in Exhibit 2-6.

The precedence table lists the tasks of a project or a phase, the tasks that must be accomplished before each other task can begin, and the estimated duration of each. The precedence diagram is developed from the precedence table. Exhibit 2-7 is the PDM representation of the Exhibit 2-6 table information.

The alphabetical task identifiers are used purely for convenience so that the entire task description does not have to be written on the node. The task leader, taking into account the experiences of previous similar task efforts, usually determines the duration of each of the tasks. It is worth repeating that the task duration estimate takes resource availability into account. Otherwise the network analysis to determine the project schedule will be meaningless.

The first step in analyzing any network is to determine the

Task Alphabetical Identifier	WBS Tasks	Precedence	Task Duration (Weeks)
a	Develop system architecture.	—	4
b	Design software modules.	a	8
c	Write code.	b	12
d	Design hardware subsystems.	a	6
e	Build hardware subsystems.	d	4
f	Write test plans.	a	2
g	Test software.	c, f	2
h	Test hardware.	e, f	1
i	Integrate software and hardware.	g, h	3
j	Test system.	i	2
k	Install system.	j	1

Exhibit 2-6. Sample precedence table.

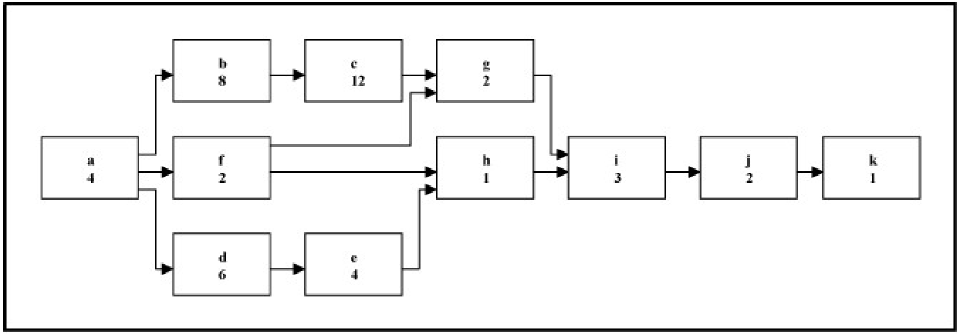

Exhibit 2-7. A precedence diagram.

early schedule—that is, the earliest each task can begin and end. The early schedule is determined by beginning at node a and working from left to right through each path. A path follows the arrows from the beginning to the end of the project. For example, tasks a, b, c, g, i, j, and k is a path. The early start (ES) and early finish (EF) of each task is recorded in the upper left and right corners, as shown in Exhibit 2-8. Starting at node a, the earliest the task can begin is at zero. The earliest it can finish is week four, since the estimated duration of the task is four weeks. The earliest that tasks b, f, and d can begin is after task a ends, or after the fourth week. Hence the early start for these three tasks is week four. Note that these times are accumulated times. That is, task b begins after a total of four weeks has been expended in the schedule. The early start for each task is the early finish of the preceding task, except when two or more tasks feed into it, such as at tasks g, h, and i. When two or more tasks feed into a succeeding task, then the early start time is the *larger* of the preceding early finish time possibilities. Hence, ES for task g is twenty-four weeks because the EF of task c is *larger* than the EF of task f. Finally, the EF of task k, thirty-two weeks, determines the schedule for the project. That is, thirty-two weeks is the earliest that the project can be accomplished given the available resources.

Determining the late schedule—that is, the latest a task can begin and end and still meet the estimated schedule of thirty-two weeks in the example—is done by working backward through the network. The late start (LS) and late finish (LF) times are re-

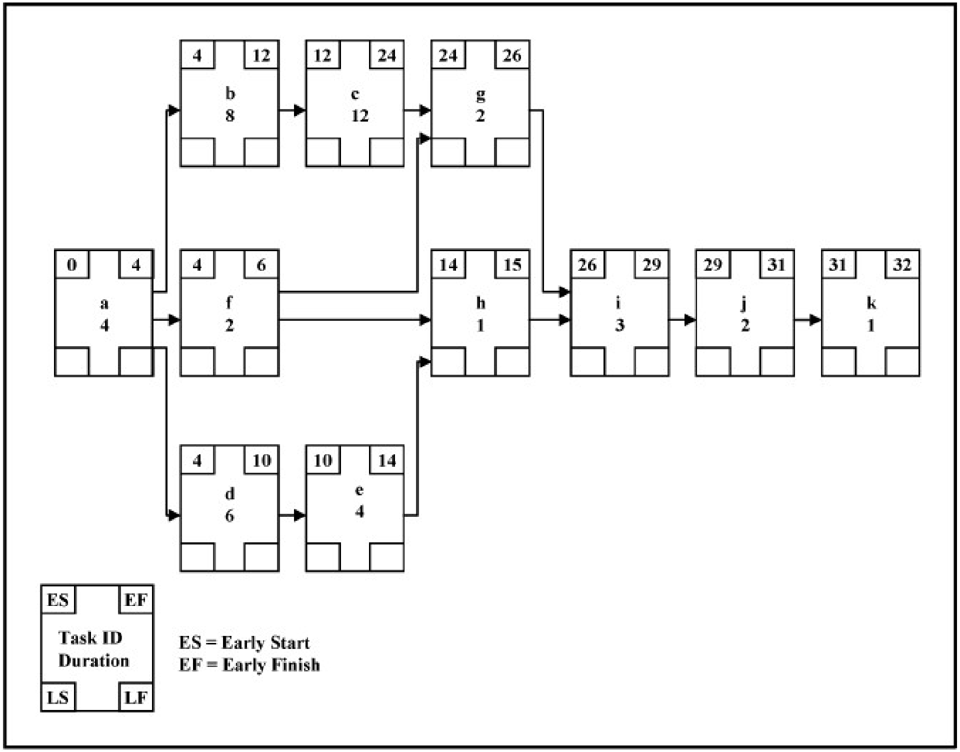

Exhibit 2-8. Network showing early schedule.

corded in the lower left and right corners of each node. To calculate LS and LF, begin at node k by recording thirty-two weeks in the LF box. The late finish of the last node is *always* the EF for that task because we want to determine how late the tasks can be started and ended *without* changing the estimated project schedule. The task duration is subtracted from the LF to obtain the LS for the task. Therefore, the late start for task k is thirty-one. The LF number for each task is the LS of the succeeding one. Thus, the LF for task j is thirty-one. The LS and LF for each task is calculated in the same manner backward through the network, except where two or more arrows back into a node. In those instances, such as for nodes f and a, then the LF is the *smaller* of the two LS possibilities. The completed network with the early and late schedules is shown in Exhibit 2-9. The heavy arrows indicate the critical path (i.e., the longest path through the network).

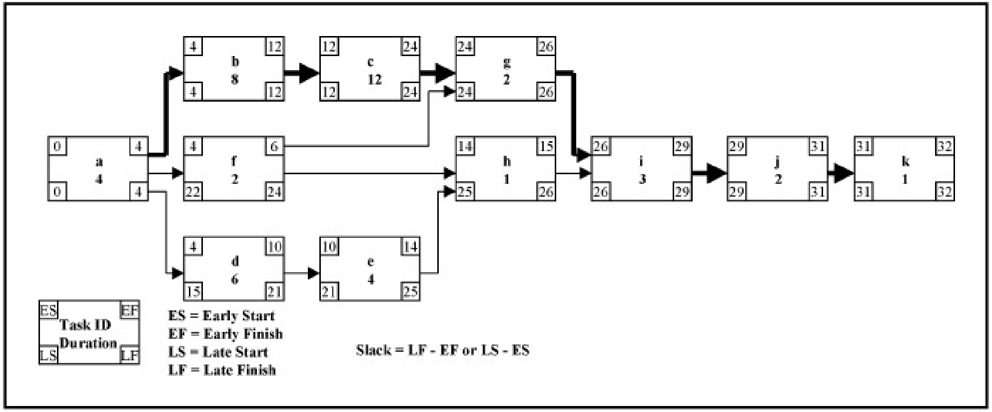

Exhibit 2-9. Completed network showing late schedule and critical path.

Slack (sometimes referred to as float) is calculated by subtracting the EF from the LF of a task. For example, the slack in task h is: LF — EF, which equals 26 — 15, which equals 11 weeks. Note that tasks a, b, c, g, i, j, and k do not have any slack. Not having slack on a path is also a defining characteristic of a critical path, and the tasks on it are called critical tasks. Critical in the context of network analysis means that if any one of those tasks slips, then the project schedule is affected. Hence, it is vital that these tasks be accomplished on time or ahead of schedule, but not later than planned.

The Gantt Chart

The WBS is the basis of all project schedules because it decomposes the project into the required tasks and allows the team to estimate each task's duration. The PDM provides a network showing the earliest and latest start and end times for each task and for the entire project. With that information at hand, Gantt charts can be prepared, graphically showing task, phase, and project schedules.

Henry L. Gantt, a pioneer in scientific management, developed the Gantt chart around 1917. It is a bar chart that shows planned and actual progress for a number of tasks displayed against a horizontal time scale. This type of information display is still one of the most effective and useful tools of project management. In addition to its use as a tracking tool for actual against planned progress, it is a very effective communications tool because it can portray a lot of data quickly to the interested parties. Exhibit 2-10 shows a sample of a Gantt chart using the WBS information from Exhibit 2-6. Although it was constructed with Microsoft Project, all other project packages produce similar schedules.

Projects are tracked and controlled using the Gantt schedules, earned value analysis, and change control processes. The change control process is discussed in Chapter 3 in detail, but earned value, the fourth major project tool, is discussed in the next section.

Earned Value

The basis of project control is still the WBS because it defines the project scope and describes the effort necessary to accomplish the project objectives. Earned value, which is a technique for tracking progress against actual accomplishment, is based on the WBS budget and schedule estimates. The Gantt chart facilitates the earned value analysis by providing a quick reference for percentage completion, a necessary input to the earned value formulas.

An earned value analysis is not particularly difficult from a mathematical viewpoint. The formulas are simple and require only straightforward arithmetic manipulations to arrive at a snapshot of how well the project is progressing. The difficulty is that it uses terms that are not familiar to us, and schedule is measured in terms of dollars instead of time. Since measuring schedule in this fashion goes against intuition and experience, some people focus on the language rather than the concepts of earned value, making learning to use the technique harder than it should be.

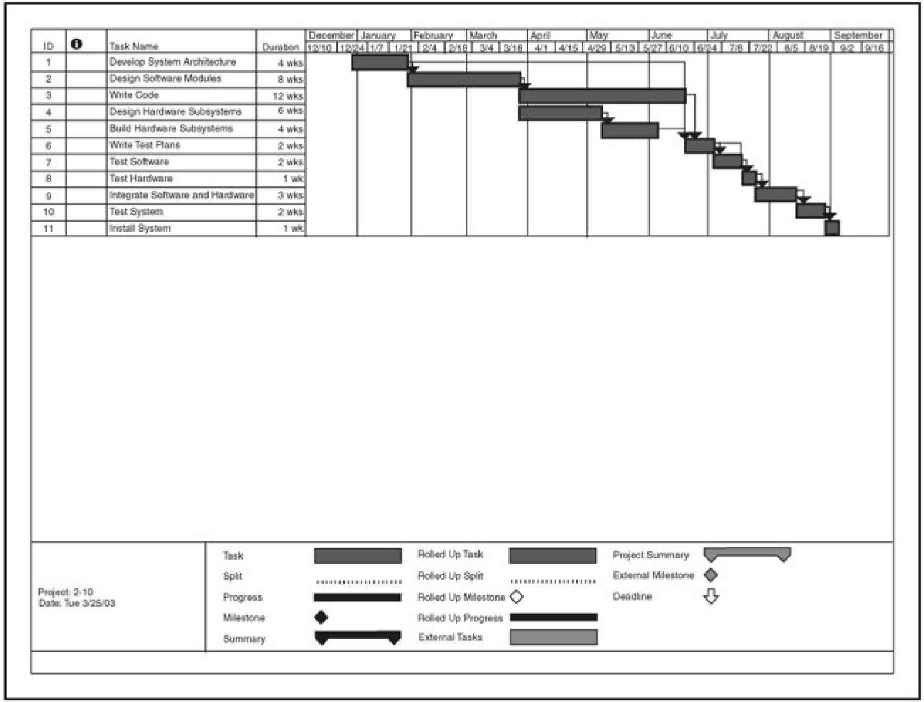

Exhibit 2-10. A sample Gantt chart.

The key to understanding earned value is in understanding three terms: planned value (PV), actual cost (AC), and work performed (EV). These three terms previously were known, respectively, as budgeted cost of work scheduled (BCWS), actual cost of work performed (ACWP), and budgeted cost of work performed (BCWP). EV is also known as the earned value, hence the origin of the name of this technique.

Once these three terms and the concepts behind them are mastered, the rest of earned value analysis is easy to understand and use.

Planned Value

PV is simply the task or project budget. Each task of the project has an estimated cost, so its PV is the amount of money identified for the expected or scheduled work to be done during execution. Each task has its own planned value. The accumulation of all these individual PV amounts equals the total budgeted cost for the project. Again, PV is an estimated amount and represents the cost that one expects to pay for part of a task, the whole task, or the project, depending on when in time the analysis is accomplished.

Actual Cost

AC is simply the amount of money that is actually paid out in the accomplishment of a task or the project. This figure is derived from labor, material, vendor, and subcontractor costs of the tasks as work on them progresses. Usually, the project manager is provided these figures from an accounting process that tracks invoices, accounts payable from vendors or subcontractors, and the salaries of personnel assigned to the tasks.

Before the earned value technique was developed in the late 1960s, AC and PV were the figures used to track project progress.

In other words, the project manager would compare actual and budgeted costs. If the actual costs were higher than expected expenditures, then it was assumed the project was in trouble. However, comparing actual and planned budget figures alone does not take schedule into account, so the project might actually be better off than expected. For example, if a project plan included the purchase of a number of computers during month five of the schedule, but the vendor offered them at a cheaper price to take them out of inventory earlier, then the actual costs for that period would be significantly higher than originally planned. Comparing only those figures would show the project to be over budget, but all else being equal, at month five the AC would be below the planned budget. In other words, more was spent at a point in time, but the project was way ahead of schedule. This concept introduces EV, the next and most difficult term to understand.

Earned Value

EV is the value of the work actually completed and measured against the planned completion amount for that period. Consider, for example, that a project is estimated to cost $20,000 and, for ease of calculation, that the cost across the project duration is linear. That is, at 25 percent completion, the project should cost $5,000; at 50 percent completion, $10,000; and so on. If the task progresses according to the planned schedule, then at the 25 percent progress point, the PV and the actual work accomplished is $5,000. That is, the budget for 25 percent of the work was planned to be $5,000 (PV), and since the task was on schedule at that point, then the budget for a completed 25 percent of work was also $5,000 (EV). But suppose at the time that this project was planned to be 25 percent completed, it was only 20 percent completed, or only 20 percent of the budgeted amount had been earned. Then the PV is $5,000 (25 percent of $20,000), and the EV is $4,000 (20 percent of $20,000). Hence, EV is a measure of schedule because it shows project progress—how much was accomplished against the plan.

Measurement or calculation of these three terms provides a basis for determining whether there is a cost and schedule variance from the project baseline.

Cost and Schedule Variance

Cost variance (CV) is the difference between the earned value and the actual cost of work performed. Mathematically, this relationship is expressed as:

$$CV = EV - AC$$

Schedule variance (SV) is the difference between the earned value and the planned value. The equation for SV is:

$$SV = EV - PV$$

Note that in both these equations, the first term on the right side of the equation is EV. EV is the key component for both these equations because this is the earned value term, or the amount earned toward completion of the project.

An example will better demonstrate the use of these formulas. Suppose at the planned 60 percent point for the $20,000 project, we actually have only completed 50 percent of the work. At this point, then, the PV is $12,000 and EV is $10,000. Suppose further that the actual moneys expended for the work accomplished is $8,000. The cost variance is:

$CV = EV - AC$

or $CV= 10{,}000 - 8{,}000$

and $CV = \$2{,}000$

A positive CV indicates that the project is under budget. A negative CV then indicates that the project is over budget. Of course, if the CV equals zero, then we are on budget.

The SV for this task is:

SV = EV – PV

or SV = 10,000 – 12,000

and SV = – $2,000

A negative SV indicates that the project is behind schedule, a positive SV indicates that we are ahead of schedule, and a SV equal to zero means that we are exactly on schedule.

There are several other mathematical terms and equations important to the earned value techniques. These are the cost performance index (CPI), the schedule performance index (SPI), the budget at completion (BAC), the estimate to complete (ETC), and the estimate at completion (EAC). Each of these terms and their representative equations are discussed in detail below.

Schedule and Cost Performance Indexes

The SPI and CPI provide the same information as the SV and CV measures, except they are shown in terms of efficiency as opposed to pure numbers. This way of presenting the project status has some distinct advantages.

SPI is calculated by dividing the earned value by the planned value. Notice that these are the same components used to calculate schedule variance. Mathematically, SPI is represented by:

SPI = EV/PV

Or, using the previous example:

SPI = 10,000/12,000

SPI = 0.83 (rounded to the nearest 100th)

If the SPI is less than 1.0, then it is behind schedule. If it is greater than 1.0, then it is ahead of schedule, and if it is 1.0, then it is exactly on track. Another way of looking at SPI is that for every dollar of physical work that the project planned to accomplish, only eighty-three cents was actually completed.

CPI is a measure of how much of the task or project value is earned against its actual cost to that point. It is calculated by dividing the earned value by the actual cost. Again, these are the same components used in the previous example to calculate the cost variance. Mathematically, CPI is described by:

CPI = EV/AC

or CPI = 10,000/8,000

CPI = 1.25

The interpretation of CPI is that for every project dollar spent, $1.25 of physical work is accomplished. That is, the project is earning more than it is spending.

Clearly, if CPI is less than 1.0, then the project is over budget (i.e., spending more to accomplish less). Likewise, if CPI is greater than 1.0, then the project is under budget, and a CPI equal to 1.0 shows the project is exactly on budget.

Both these indexes are more useful than the variance calculations for communicating progress to the stakeholders. A pure number (e.g., CV = – $100) has no meaning to someone not intimately acquainted with the project and its finances because $100 more or less gives no indication of how good or bad the project is doing. For example, if the EV is $2,000 and the AC is $2,100, the CV is still $100. But the CPI is now 0.95 (2,000/2,100), which indicates that the project is under budget, but not by very much relative to total amount earned or spent—and certainly not so much as to require drastic recovery actions. That is not true in a case where CV equals – $100 and the CPI = 0.67, which occurs when EV is $200 and AC is $300. In the latter case, the project can only survive if drastic measures are not taken, and even then, the project will most likely not ever recover to a point of finishing on budget. Thus, the SPI and CPI indicators are excellent for use in status reporting and managing projects because they more accurately portray the true project status. These indexes also are important in predicting how much additional time or money may be needed to complete a project.

Estimates at Completion

The SPI and CPI are used to calculate final schedule and budget figures. For instance, suppose in our example the task originally was estimated to require ten weeks to complete. A new or latest schedule estimate (LSE) at completion can be calculated by dividing the original schedule at completion (SAC) estimate by the SPI. The latest schedule estimate is represented by:

LSE = SAC/SPI

or LSE = 10/0.83

LSE = 12.05 (rounded to nearest 100th)

Hence, the new schedule requirement is just over twelve weeks if nothing is done to improve the schedule from this point forward.

Likewise, a latest revised budget estimate (LRE) is calculated by dividing the original budget at completion (BAC) by the CPI. Mathematically this calculation is provided by the equation:

LRE = BAC/CPI

or LRE = 20,000/1.25

LRE = $16,000

So the new estimated cost of the total task is now $4,000 less than originally estimated. However, the CPI and SPI must be interpreted together. That is, the indication is that the project is under budget but behind schedule. This might be because some of the scheduled tasks are not completed or, worse, have not begun. The project manager's task is to determine not only why the project is under budget, but also why it is behind schedule and what the impacts to the project are.

Some practitioners use CPI and SPI together to obtain worst- and best-case budget estimates at completion. That is, the CPI alone will provide the best-case estimate. The product of multiplying CPI and SPI provides the worst case, since multiplying two fractions yields a smaller fraction and includes the schedule impact. To demonstrate, multiply our CPI of 1.25 and SPI of 0.83 to obtain 1.04 (rounded to the nearest 100th). Then calculate a new LRE as follows.

LRE = BAC/1.04

or LRE = 20,000/1.04

LRE = $19,230.77

Hence, the new budget estimate falls within the range of approximately $16,000 and $19,000. In actuality, the new estimate at completion for the budget will probably not be as good as the $15,000, nor as bad as the $19,000, but rather something in between, depending on how well the schedule recovers with project management intervention.

One final calculation is important in the earned value analysis process, and that is the estimate to complete.

Estimate to Complete

ETC provides the project manager with an estimate of the amount of money required from a point in time to the estimated end of the project. This figure is important for two reasons. First, the project manager has to know how much additional funding may be required. If nothing can be done to improve the budget picture, then either the customer must agree to additional funding, or the organization must absorb the loss. Naturally, the project manager will endeavor to get the project back on track, but knowing how badly the project is faring will provide insight into what actions need to be taken for recovery. The second reason ETC is important is that the financial organization needs the information for planning future cash flow requirements.

The ETC is calculated by subtracting the actual amount expended on the project from the latest budget estimate at completion. Mathematically, ETC is calculated by this equation:

ETC = LRE – AC

or ETC = 16,000 – 3,000

ETC = $13,000

Exhibit 2-11 is a useful table of the most important earned value formulas and their definitions. Exhibit 2-12 is a graphical depiction of the earned value analysis.

Term	**Definition**	**Formula**
PV	Planned value of the work scheduled or the estimated cost of each task or project.	PV for project = Total budgeted cost for each of theproject tasks. PV for a task is total task budget.
AC	Actual cost to accomplish the work. Money expended to accomplish the EV.	AC = Total of all actual costs (labor, materials, vendor, and subcontractor costs) at time of status checkpoint.
EV	The budgeted amount "earned" or completed against the planned amount.	EV = (% of tasks completed) × PV of project or task as appropriate.
CV	Cost Variance. The difference between the amount earned, that is EV, and the actual expenditures, AC.	CV = EV – AC
SV	Schedule Variance. The difference between the amount accomplished or earned, EV, and PV, the amount planned.	SV = EV – PV
CPI	Cost Performance Index. A measure of the amount earned per each dollar expended.	CPI = EV/AC
SPI	Schedule Performance Index. A measure of the physical work accomplished per each dollar expended.	SPI = EV/PV
SAC	Schedule At Completion. The total project schedule duration.	SAC = Total project schedule

BAC	Budget At Completion. The total project cost	BAC = Total project cost
ETC	Estimate To Complete. The amount of money needed to finish the project from the point of each status checkpoint.	ETC = BAC (or LRE) —AC
LRE	Latest Revised Estimate. The mostrecent budget estimate for total project cost.	LRE = BAC (or previous LRE)/CPI
LRS	Latest Revised Schedule. The most recent total project duration estimate	LRS = SAC (or previous LRS)/SPI

Exhibit 2-11. Earned value terms, definitions, and formulas.

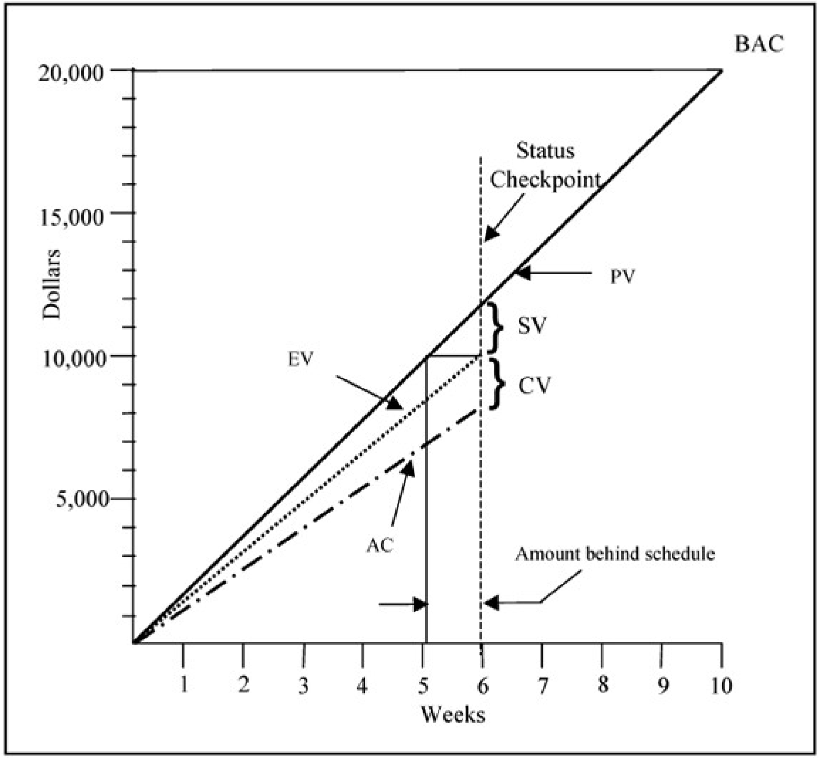

Exhibit 2-12. Earned value graph.

Summary

The vast majority of all information technology projects fail, principally because organizations cannot adapt their management and support processes to the rapid change of technology. These projects also fail because companies don't have the expertise to develop themselves into project-oriented organizations, and, therefore, are unable to put into place the project management techniques and tools required to effectively and efficiently manage IT projects.

There are many project management tools, but the most important four are:

1. The work breakdown structure (WBS)

2. The network analysis

3. The Gantt chart

4. The earned value analysis

Of these four, the most important is the WBS, because with a complete and accurate WBS, the project manager can develop every other tool she needs.