11

Project Management's Role in Life Cycle Costing

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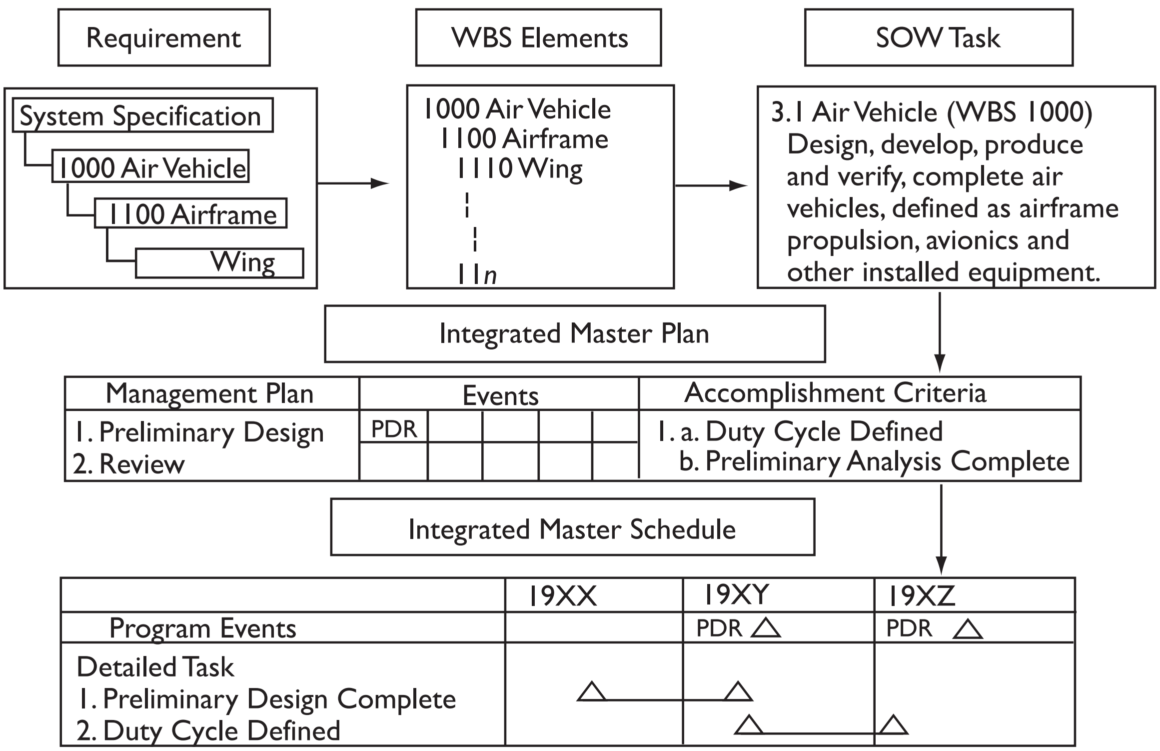
11.1 Introduction

Formal project/program management, are essential in planning, controlling, and communications that, when properly executed, supports time and cost estimates and is needed to manage any project/program. As shown in Figure 11.1, requirements map to work breakdown structure (WBS) elements, which ultimately feed a master schedule.

Figure 11.1. Role of WBS in Developing an Integrated Master Schedule (from DAU, 2001)



Much of the literature concerning scheduling and project management concepts focus on the mechanics of project management (networks, CPM, etc.) of the project, those concepts may also make much more of an impact if they are implemented early in the planning and design stages of a project. Most of the control of the project cost and duration takes place in its early planning stages. In Figure 11.1, you can see that most of the influence of the cost and scheduling of a project occurs in its early planning. For example, the ultimate decision as to have a project happens in the beginning. As planning proceeds, decisions are made that determine the characteristics of the project, such as, size of the facility, the technology to be used in the facility, and the quality of the facility. As the project moves to design, further decisions nail down cost and schedule. The contractor is left to influence only the cost and scheduling aspects of the project. Managing labor and equipment productivity, smart buying, and the use of good project management practices can accomplish this. Effective project management concepts must be initiated early in the planning of a project and continue throughout its life cycle.

11.2 Basic of Networks

Simply put, time is money and the duration of a project has a direct bearing on its cost. Because the estimated duration of any project is determined by a schedule; and the activities coordinated by that schedule, project planning is an important element of any engineering/technology project.

Much of the current thinking equates scheduling to a network. While this is not necessarily true, let us examine the concept. A *network* is a diagram of activities joined in interconnected links that reflect relationships between complex interrelated tasks. It is used to determine the overall duration of a project, to learn about the project, to perform "what-if" analyses, and to analyze and settle issues. There are claims that a network can integrate cost and schedule but, as desirable as this is to the management of construction, it rarely is done in practice.

Basically, there are two types of networks. The first is the "activity-on-arrow" network. In this type, the arrows represent activities, while the nodes represent events. This is predominantly used in construction and is taught in most management science courses. The second is the "activity-on-node" or precedence network. In this type of network, the nodes represent activities while the arrows represent only interrelationships. Modern project planning software uses activity-on-node networks. Both network types have been used in the CPM and in PERT (Program Evaluation and Review Technique). However, much of the software is moving toward only supporting the precedence-type networks.

CPM and PERT were developed independently in the late 1950s. CPM was developed by Morgan Walker of E.I. Dupont and James E. Kelly, then with Remington Rand Univac Corporation. The goal of the research that ultimately led to CPM was to reduce time for the construction and maintenance of manufacturing plants. CPM is a deterministic method that assumes that at least one path through the network determines the project duration and that path is the "critical path." PERT was developed by a research team consisting of the U.S. Navy Special Projects Office and the consulting firm of Booz, Allen, and Hamilton for planning and control of the production of the Polaris submarine in the late 1950s. PERT is a stochastic technique that assumes one path determines the duration of the project. It is based on the assumption that the duration of a single activity can be described by a probability density function. The duration of the project is computed by the sum of the "expected" durations of each activity on the critical path. Then, because of a specific statistical theorem (the Central Limit Theorem), the duration of the project can be shown to follow a bell-shaped (normal) distribution, uniquely defined by the parameters computed from the individual activity parameters (Stevens, 1990).

One other networking technique coming into favor with the advent of faster and more powerful microcomputers is the use of simulation networks. By assuming specific distributions for individual activities, networks can be repeatedly computed using random influences, the outcomes plotted and the overall duration distribution approximated. Most modern project management software contains this capability.

You must remember that a network is not a schedule. The network is used to develop scheduling data. Once the data are developed, you may produce a schedule in the form of a table or bar chart.

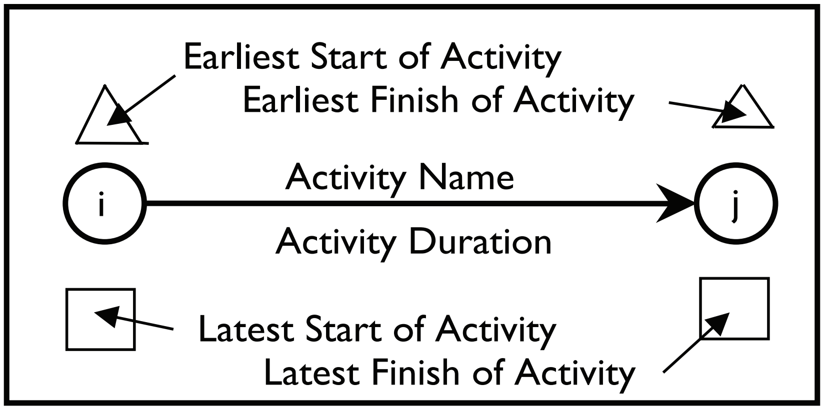
Networks are the cornerstones of any type of program or project planning. In the civil engineering profession the PERT/CPM network is the primary tool for planning (choosing which method or procedure should be used), scheduling (time of the procedures) and controlling (monitoring the procedures). The terms PERT and CPM are used interchangeably and together because it has become common terminology for networks in the construction and engineering communities when referring to the whole networking technology. We shall use the term CPM unless stochastic time duration is introduced.

A project has been identified as a collection of activities interrelated logically or sequentially, that has a finite scope. Projects related to civil engineering planning and are typically non-repetitive, and not conducted at the same site. A CPM network consists of the logical relationships between the activities that make up a project. There are two types of CPM networks. The first is the arrow diagramming method (ADM) also called the "activity-on-arrow" method. The second is the precedence diagramming method (PDM). The ADM has historically been more popular in the civil engineering and construction communities. However, the PDM is increasing in popularity primarily due to some of the newer features of some of the CPM software packages. Primavera® and Microsoft Project® use only PDM networks. However, most texts use ADM networks to teach the basics of networks.

11.2.1 Development of the ADM Network

The basic building block in a project network is the activity. In an ADM network, an arrow as shown in Figure 11.2 represents that activity. The beginning and endpoints of activities are called *events*. These events are typically referred to as nodes in the network and are represented by the circles shown in Figure 11.2.

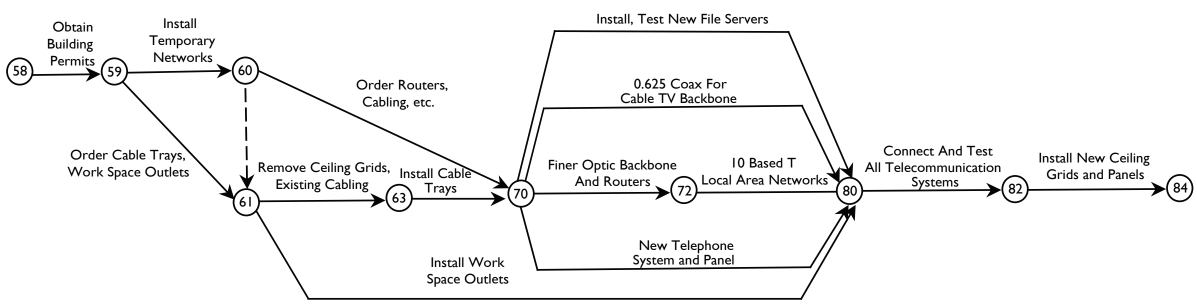
Figure 11.2. Basic Elements of ADM Network



All CPM networks follow this set of basic rules:

1. The network must have one starting (without a predecessor), and ending node (without a successor) representative of project initiation and completion, respectively;
2. Before any activity can begin, all activities preceding that activity must be complete; and,
3. Any two events can be connected by only one activity.

Example 11.1. The relationships for an ADM network without durations for the installation of a telecommunications system are shown. Note that this final network was developed after careful review of the drawings. Several drafts were prepared before the final drawing was complete. This figure looked much different from when it was first drafted.



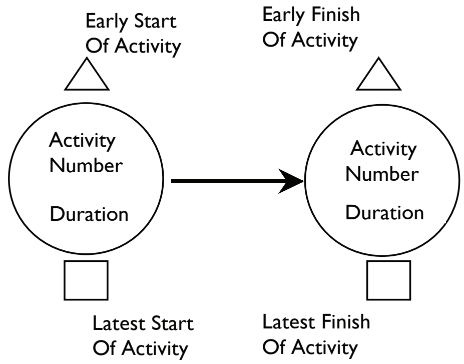
Often a *dummy* activity must be introduced to correct problems of false dependency, and to satisfy the three basic CPM rules. Loops are prevented by "dummy" arrows (represented by a dashed line from activity 60 to 61 in Example 11-1). Dummy activities are also a tool that permits some logic restrictions. A dummy arrow shows dependence only. It implies no duration. The number of dummy arrows in a network should be minimized. Figure 11.3 demonstrates the use of dummy activities.

Each activity is uniquely identified by its i,j number. In an ADM, this determines the activity's relationship within the network. All computer software packages use the i,j number as the activity identifier. It must be unique. Two activities with the same i,j number form a loop causing an error in the network.

Generally speaking, the network is made up of several "paths" that consist of activities that must be performed sequentially. For instance, the path of remove existing ceiling grids and cabling; install cable trays, fiber optic backbone, routers, local area network; connect and test; and install new ceiling grids follow logically in Example 11-1.

In a PDM network, a node or event (Figure 11.3) represents the activity.

Figure 11.3. Basic Elements of a PDM Network



Here are some PDM network development guidelines:

1. Unlike ADM, the PDM activity is identified by a node-number. This number has nothing to do with the logical dependencies of the network. It is merely an identifier;
2. In working with various software packages, you must describe each activity's predecessor and its successor explicitly; and
3. There are no dummy arrows in a PDM network.

11.2.2 CPM Calculations

Although most complex networks will be computed using computer software, you should have some understanding of how those calculations are made. This does not mean that an engineer should waste time calculating network data by hand unless software is not available. These steps are necessary to perform CPM calculations:

1. Estimate activity duration's,
2. Perform a forward pass,
3. Perform a backward pass,
4. Compute the total float, and
5. Compute the free float.

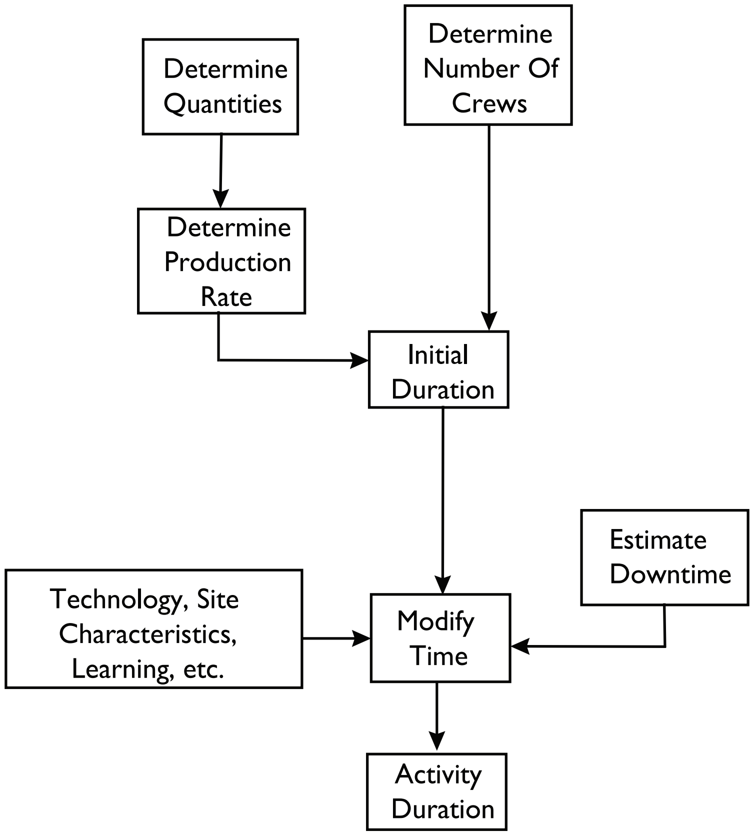
The most difficult aspect of scheduling is probably estimating an activities duration. It is like estimating the cost of an activity. You must know the construction methods to be used, the resources available, the quantities involved and, most important, the production rate. Those subjects will be discussed in great detail in section 3 on Activity Planning. From a practical point-of-view, most planners will use various handbooks that give crew requirements, production rates, and unit prices. Figure 11.4 shows the general algorithm for developing the durations of activities. Using Equation 11.1, the duration of an activity for an ADM network is computed by:

$$T_{ij} = \frac{Q_{ij}}{n_{ij} N_{ij}} + DT_{ij} \qquad (11.1)$$

where:

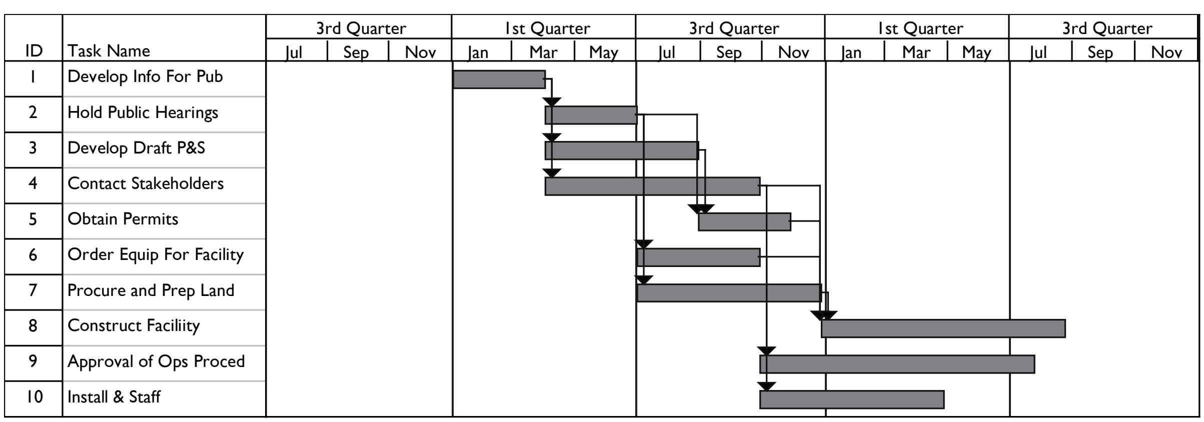
T_{ij} is the duration of the activity,
Q_{ij} are the quantities being acted on by the controlling resource,
k_{ij} is the number of crews of the controlling resource,
N_{ij} is the production rate of the controlling resource, and
DT_{ij} is the downtime associated with the controlling resource.

Figure 11.4. Activity Duration Estimation Algorithm



The bar chart is probably the most often used project management tool. Numerous forms of the bar chart exist for conveying information. The bar (or Gantt) chart can be very effective for conveying a simple schedule. Figure 11.5 is a Gantt chart for the hazardous waste problem. This chart was produced using Microsoft Project®.

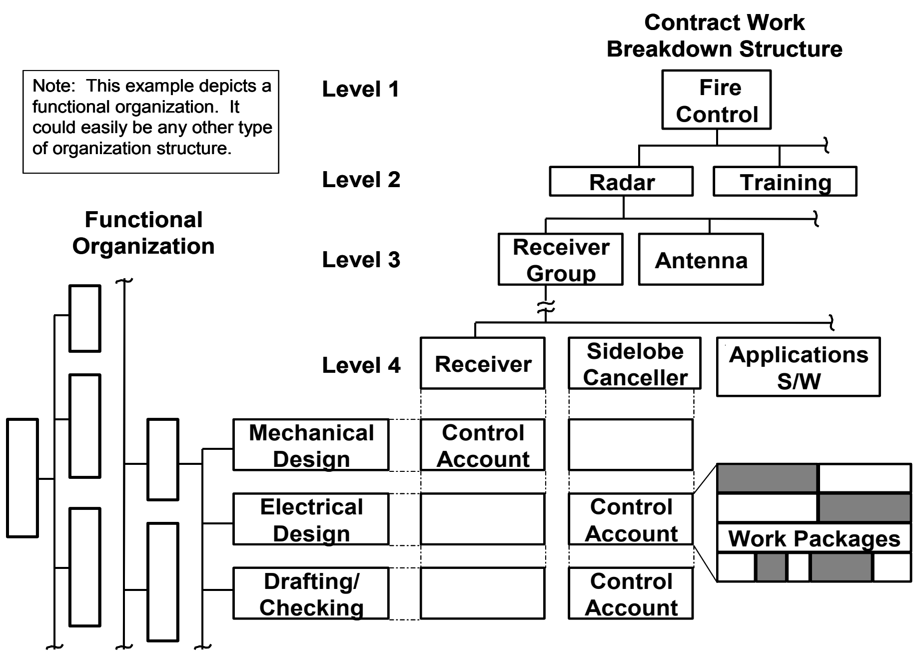
Figure 11.5. Gantt Chart of the Hazardous Waste Incineration Facility



11.3 Work Breakdown Structure (WBS)

Most projects will be broken down into sub-elements. This must be done, at least implicitly, on any but the smallest projects, to schedule the activities. The WBS will be used to assign responsibilities and for management control on major complex projects, and to develop activities for project scheduling. It is also used in the planning stage to identify tasks and subtasks. For smaller projects, the WBS can be used for cost accounting and the assignment of responsibilities. There are no hard and fast rules as to the level of detail that goes into developing a WBS. Figure 11.6 shows the relationship between system design and architecture and a WBS.

Figure 11.6. Relationship Between System Design and WBS (from DoD, 2005)



11.4 Progress Measurement

Here are numerous methods available to measure work in progress of an activity. Some depend on judgment; some may be calculated analytically. We discuss seven methods used to assess performance or measure work. You must be cognizant of the potential for abuse when at least seven methods exist for measuring performance.

Method 1: Units Completed. This assumes that the activity is basically linearly scheduled. If the activity is one such as pouring 800 cubic yards of concrete and 400 cubic yards have been poured, then the progress is 400/800 = 0.5 or 50% complete.

Method 2: Incremental Milestones. This method depends upon heuristics based on experience. If the activity is one of those presented here, then the progress may be estimated as shown in Table 11-1 for a typical construction project.

Table 11.1. Incremental Milestone Method of Progress Measurement

General:	Received And Inspected	15%	Structural Steel:	Matl Received & Shakeout	5%
	Setting Complete	35%		Erection	55%
	Alignment Complete	50%		Plumb, Bolt Up, Weld	35%
	Internals Installed	75%		Grout	5%
	Testing Complete	90%			
	Accepted By Owner	100%			
Foundations:	Excavation	5%	Finished Building:	Foundation & Slab Walls	20%
	Form Work	50%		Erected	20%
	Rebar/Embeds	20%		Roof	10%
	Pour & Finish	10%		Interior Walls	20%
	Strip and Finish	10%		Finishes & Trim	25%
	Backfill	5%		Punch-list	5%
Piping:	Underground Trenching:	10%	Electrical:	Material Received	5%
	Receive & Layout Material	5%		Conduit Runs	25%
	Lay Pipe	30%		Junction/outlet boxes	20%
	Joint Pipe	50%		Cable Pulling	20%
	Test & Backfill	5%		Connections	25%
				Testing	5%

Method 3: Start/Finish. Some activities may have a duration shorter than the reporting period. In that case, it may go to 100% in the period and its progress measured accordingly.

Method 4: Supervisor Opinion. Painting, dewatering, constructing support facilities, installing architectural trim, and landscaping are candidates for this approach.

Method 5: Cost Ratio. Project management, quality assurance, contract administration and project controls are candidates for this approach. This is not a good measurement for physical activities that require actual work.

$$\text{Percent Complete} = \frac{\text{Actual cost or work-hours to date}}{\text{Forecast at completion}} \qquad (11.2)$$

Method 6: Weighted or Equivalent Units. Material weights or some similar unit can be used to measure progress. This is illustrated using the data in Table 11-2.

Table 11.2. Weights and Quantities for a Small Steel Building

Wt.	Subtask	u/m	Quan Total	Equiv stl ton	Quantity to-date	Earned Tons
0.02	Fdn bolts	each	200	10.4	200.0	10.4
0.02	Shim	%	100	10.4	100.0	10.4
0.05	Shakeout	%	100	26.0	100.0	26.0
0.06	Columns	each	84	31.2	74.0	27.5
0.10	Beams	each	859	52.0	0.0	0.0
0.11	Cross-braces	each	837	57.2	0.0	0.0
0.20	Girts & sag rods	bay	38	104.0	0.0	0.0
0.09	Plumb & align	%	100	46.8	5.0	2.3
0.30	Connections	each	2977	156.0	74.0	3.9
0.05	Punchlist	%	100	26.0	0.0	0.0
1.00	STEEL	TON		520.0		80.5

Progress is measured using Equations 11.3 and 11.4.

$$\text{Earned Tons to Date} = \frac{(\text{Quantity to date})(\text{Relative weight})(520\ \text{tons})}{(\text{Total Quantity})} \qquad (11.3)$$

$$\text{Percent Complete} = \frac{\text{Earned Tons To Dates}}{520\ \text{tons}} = \frac{80.5\ \text{tons}}{} = 15.5\% \qquad (11.4)$$

Method 7: Earned Value. Earned value is the preferred method of progress measurement by most agencies and contractors. This method uses man-hours or dollars as a way to weigh the value of one activity with respect to the others. It has nothing to do with the actual consumption of person-hours or dollars on a project. To perform an earned value analysis on a project, first you must find the percent complete of each activity. This may be done using methods 1 through 6. That percent complete is then multiplied by the budget in person-hours, person-days, or dollars for that activity. That gives the earned value for that activity, and is often referred to as the Budget Cost of Work Performed (BCWP) for that activity. The earned value for the project is given by:

$$\text{Percent Complete} = \frac{\text{Earned work-hours or dollars all accounts}}{\text{Budgeted work-hours or dollars all accounts}} \qquad (11.5)$$

11.4.1 Evaluation of CPM

These terms are gaining acceptance in the construction industry with regard to assessing progress with networks:

1. Budgeted Cost of Work Scheduled (BCWS),
2. Budgeted Cost of Work Performed (earned value amount) (BCWP), and
3. Actual Cost of Work Performed (ACWP)

The terms are used to calculate various indicators or program performance are:

$$\text{Schedule Variance (SV)} = \text{BCWS} - \text{BCWP} \qquad (11.6)$$

$$\text{Schedule Performance Index (SPI)} = \frac{\text{BCWP}}{\text{BCWS}} \qquad (11.7)$$

$$\text{Cost Variance (CV)} = \text{ACWP} - \text{BCWP} \qquad (11.8)$$

$$\text{Cost Performance Index (CPI)} = \frac{\text{BCWP}}{\text{ACWP}} \qquad (11.9)$$

Figures 11.7 and 11.8 show numerical values of those indicators that can be interpreted differently. Figure 11.7 shows BCWS, BCWP, and ACWP can be used to reflect various degrees of completion over the life of a project. A time plot of these performance indicators can be useful to identify when projects are starting to fall behind schedule, occurring cost overruns, etc.

Example 11.4. Your bonding company has asked for the status of a telecommunications revitalization project (Example 11.1). You decided to calculate SV, SPI, CV, and CPI as performance indicators. Your cost accounting section and project manager has provided you with the following information:

Activity Number	Description	Total Cost Forecast	Percent Complete	Cost To Date Actual	Cost To Date Forecast
58,59*	Building Permits	$ 2,000.00	100.00%	$ 1,253.75	$ 2,000.00
59,60*	Temp Networks	$ 25,000.00	100.00%	$ 26,497.83	$ 25,000.00
59,61	Order Cable Trays	$ 8,000.00	100.00%	$ 7,907.27	$ 8,000.00
60,70	Order Routers, Cabling	$ 10,000.00	100.00%	$ 9,017.32	$ 10,000.00
61,63*	Remove Ceilings	$ 18,000.00	100.00%	$ 11,427.49	$ 18,000.00
63,70*	Install Cable Trays	$ 28,000.00	100.00%	$ 19,743.19	$ 28,000.00
70,80*	New Servers	$ 20,000.00	70.00%	$ 11,271.25	$ 14,000.00
70,80	Cable TV	$ 10,000.00	10.00%	$ 793.21	$ 1,000.00
70,72	Backbone & Routers	$ 20,000.00	5.00%	$ 327.19	$ 1,000.00
72,80	LANs	$ 17,500.00	0.00%	$ -	$ -
80,82*	Connect & Test	$ 15,000.00	0.00%	$ -	$ -
82,84*	New Ceilings	$ 20,000.00	0.00%	$ -	$ -
	Total As Of 2/28/08	$ 193,500.00		$ 88,238.50	$ 107,000.00

Asterisks indicate the critical path for this project.

Solution:
You need three pieces of information to obtain the desired performance indicators: BCWS, BCWP, and ACWP. BCWS is simply the total cost forecast; BCWP is the cost to date forecast; and ACWP are the actual costs to date. Thus,

SV = BCWS – BCWP = $193,00 - $107,000 = $86,500

$$SPI = \frac{BCWP}{BCWS} = \frac{\$107,000}{\$193,500} = 0.55$$

CV = ACWP – BCWP = $88,238.50 - $107,000 = -$18,761.50

$$CPI = \frac{BCWP}{ACWP} = \frac{\$107,000}{\$88,238.50} = 1.2$$

From Figure 11.8, a CPI>1 and SPI<1 indicate that the job is behind schedule but under budget. Although this analysis does not provide an absolute answer as to what is wrong with the project, it provides an indication that management should look into the performance. This pattern probably means the contractor is using an insufficient level of effort to maintain the schedule.

Figure 11.7. Performance Measurement Parameters

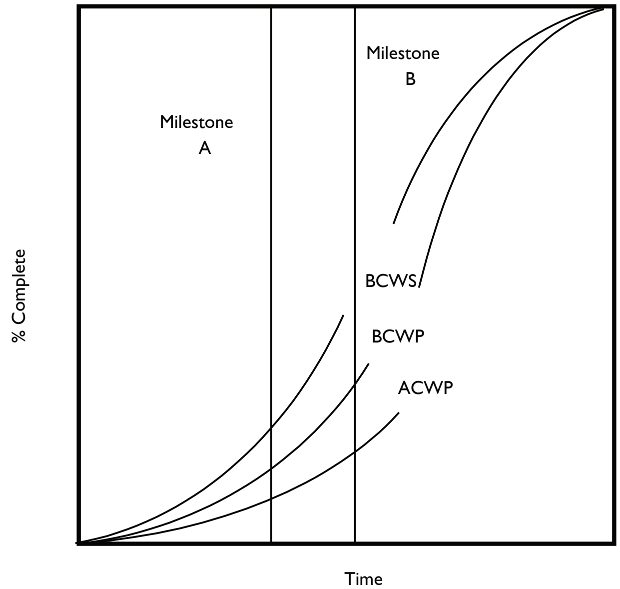
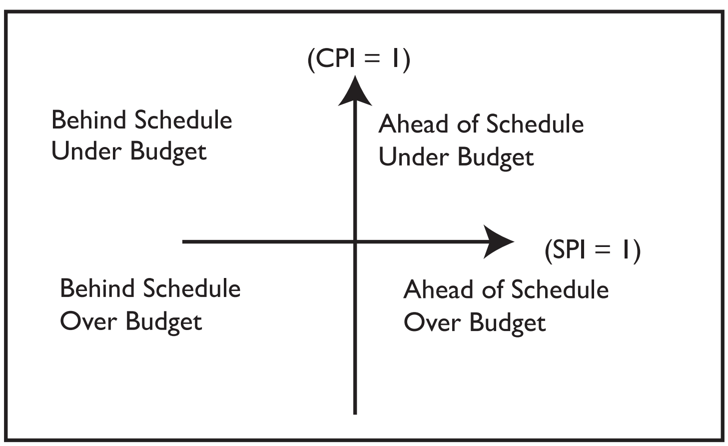


Figure 11.8 shows how values of CPI and SPI can be related to schedule and budget.

Figure 11.8. Meanings of CPI and SPI



CPI and SPI can be calculated for a single activity, a group of activities, or a whole project or program. Using SPI may not be a good schedule performance indicator.

11.5 Monte Carlo Simulation of Networks

Stochastic simulation is a technique by which a computer is used to simulate the actions of a system. Systems can generally be depicted as mathematical or logical models about which specific assumptions are made. If the model is simple enough, it may be solved explicitly. However, most complex, real-world problems cannot be solved explicitly. Thus, simulation is used to evaluate a model numerically. Data are then gathered to estimate the true characteristics of the model. A network must be treated as a system of activities.

The name "Monte Carlo" originated during World War II when it was used to solve problems related to the development of the atomic bomb. It will be used in this section as a way to study a network or a system. Monte Carlo simulation allows much more flexibility than PERT. You can assign almost any uncertain attribute of a project as a random variable, then simulate the actions of nature, collect data from the model, and predict the characteristics of the system.

The theory behind Monte Carlo simulation is simple. Each activity in the network is assumed to be an independent random variable that behaves according to some known distribution. In simulating a network, the duration of each activity is assumed to follow a probability distribution rather than being a single point estimate. The simulation process will select the duration to add for each activity randomly using random numbers selected from a uniform distribution.

11.6 Summary

Resources are labor, equipment, material, subcontractors, money, workspace, and anything else needed to perform a project. Resources determine the duration and the cost of a project. They should be viewed as the independent variables of construction management. The production rate of driving resources determines the duration of an activity. Similarly, the costs associated with driving resources are fixed regardless of the duration of an activity. If a specified amount of driving resources will complete an activity in a specific period, doubling that resource, from a purely theoretical point-of-view, should halve the duration, but the cost should remain the same.

Non-driving resources do not determine the duration of an activity. The cost of a non-driving resource may or may not vary with time. The purchase price of installed material should be the same regardless of the installation duration. However, the cost of a night watchman will increase as the duration of the activity requiring a night watchman increases.

Resource allocation and resource leveling are best accomplished using a computer. Any but the most trivial networks are difficult if not impossible to level by hand. You should note, however, that field supervisors are usually adept at establishing crew sizes and managing crews efficiently regardless of any early network gyrations. Therefore, resource leveling is most useful in preliminary planning. Prior to implementation, an experienced construction manager should evaluate any computer solution to resource allocation or leveling.

11.7 Bibliography

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