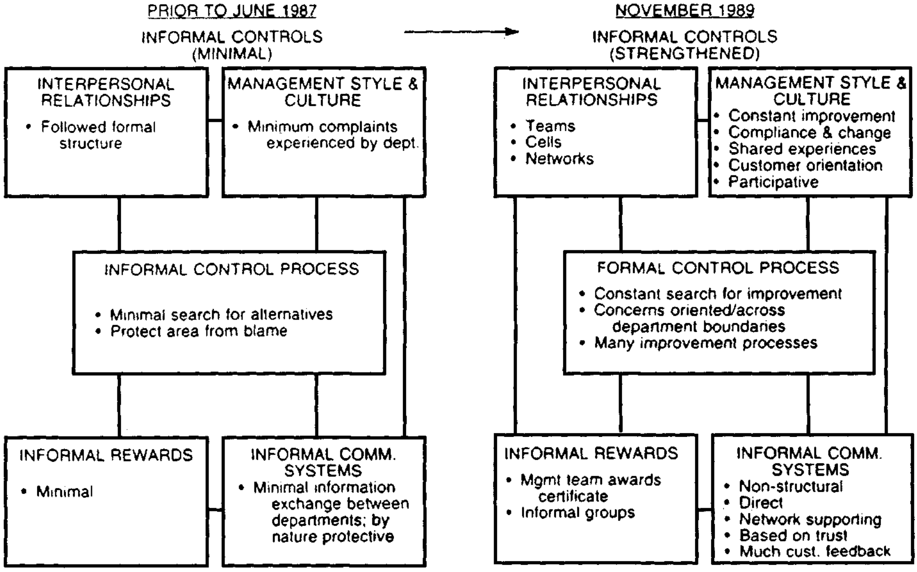


Fig. 67.13 BSY-1 Informal systems: before and during improvement effort.

67.4 SPECIFIC ISSUES IN THE PROJECT-CONTROL PROCESS

67.4.1 Project-Planning and Control Process: Overview

Figure 67.14 summarizes the project-planning and control process. The process provides for planning according to goals and requirements and control by exception. The process is initiated by establishing detailed project requirements, and in meeting them, we simultaneously achieve the goals of a project.

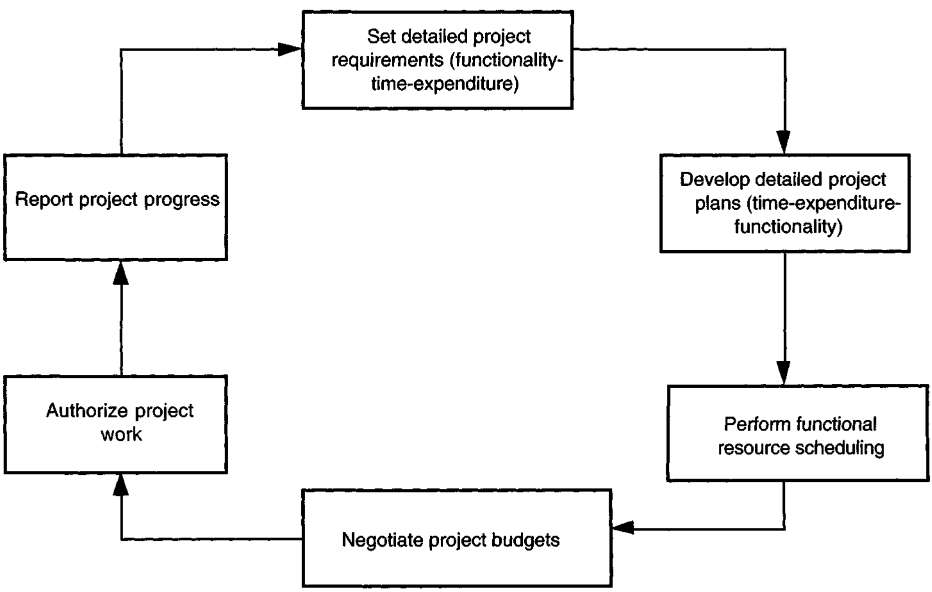


Fig. 67.14 Summary of project-control process.

Detailed requirements are established by preparing a means–end work breakdown structure (WBS), which is a hierarchical subdivision of a project. The WBS provides the framework within which we may establish project requirements and prepare detailed plans for the time, expenditures, and performance variables of the project.

Once all end items (purposes and subpurposes) of the project have been established, the next step of the process requires logical, consistent, and coordinated plans to achieve the end items of the project. Network analysis provides a tool for identifying functional activities that must be performed to achieve a lowest-level end of the WBS. That is, in putting together the detailed plans for a complex project, we begin at a level of detail where we can identify functional activities with which we have had some prior experience and in this way break up the novel task into its known elements. This process tends to reduce the novelty of a complex project.

Network plans and the WBS provide the basis for estimating the expenditures of a project. Labor, material, and overhead costs assigned to each lower-level item of a WBS may be derived from estimates of activities contained on networks. By summarizing vertically (i.e., up the WBS) all expenditure estimates beginning at the lowest level of the WBS, we may arrive at expenditure estimates for any other level of the WBS. Standard costs do not exist for complex projects and must be established on an individual project basis.

From detailed network plans, constructed for each lowest-level end item of the WBS, detailed schedules are developed in *each* function, with the goal of achieving the plans of the project. During the resource-scheduling process, functional managers allocate their functional resources among competing projects to maximize compliance with all the project plans of the organization.

Financial planning must be done for the total project, yet the financial plan so derived cannot be utilized directly as a budget, since its construction assumes that activities will be accomplished in a manner considered optimum from the point of view of the project. The need to balance resources among projects, observe institutional rules, and react to unexpected project change often requires us to accept less than optimum resource allocations. This means that *actual* resource allocation or scheduling decisions can be made only for those activities to be accomplished in a relatively short period of time, since long-range schedules would depend on long-range demands placed on a function by all projects, and these demands cannot be predicted with accuracy.

Once these allocation decisions are made, a block of work represented on the network, derived from the WBS, is authorized. The project-control process then turns to activities of control. Project office personnel are concerned with controlling actual performance to achieve a balance among expenditure, time, functionality, and quality variables of a project. Since we are required to achieve balance among these variables, our project-control system must contain and process progress information on each of these variables.

It is necessary, therefore, both to calculate variances for expenditure, time, and performance goals and to derive measures of combined variable performance whenever possible. Techniques of variance analysis are available for combining the time and cost variables into planned and actual measures of *value of work performed.* Performance variables are usually introduced in a qualitative way, although in certain circumstances, quantitative performance variances may be defined.

The reporting structure should be designed to conform to the means–end breakdown of the project contained in the WBS. It should be possible to retrieve actual versus planned data on each of the key project variables for any level of the WBS. In addition, it should be possible to summarize information horizontally to obtain detailed planned and actual data for functional organizations.

The reporting system is part of the contribution made in the project-planning and control process toward directing project effort to problem areas to resolve deviations that occur between project requirements and actual performance. It is not a substitute for a well-designed organizational structure, but it is intended to support the structure.

67.4.2 The WBS

Work Breakdown Structure and Means–End Analysis

The construction of work breakdown structures (WBS) has been a pragmatic response to the needs posed by new and complex projects. The broad outline of a theory for the WBS does exist, however, and is described by March and Simon (Ref. 10, pp. 190–191). Some of the questions regarding construction and the use of WBS's for the elaboration of activities involved in new projects can be clarified by appealing to their work regarding means–ends analysis. They state:

> *In the elaboration of new projects, the principal technique of successive approximations is means–end analysis: (1) starting with the general goal to be achieved, (2) discovering a set of means, very generally specified, for accomplishing this goal, (3) taking each of these means, in turn, as a new subgoal and discovering a set of more detailed means for achieving it, etc.*

How much detail should the WBS contain? Again referring to March and Simon (Ref. 10, p. 191):

It proceeds until it reaches a level of concreteness where known, existing projects can be employed to carry out the remaining detail. Hence the process connects new general purposes with an appropriate subset of existing repertory of generalized means. When the new goal lies in a relatively novel area, this process may have to go quite far before it comes into contact with that which is already known and programmed; when the goal is of a familiar kind, only a few levels need to be constructed of the hierarchy before it can be fitted into available programmed sequences.

The objective of the WBS, therefore, is to take innovative output requirements of a complex project and proceed through a hierarchical subdivision of the project down to a level of detail at which groups of familiar activities can be identified. Familiar activities are those for which the functional organizations have had some experience. What is familiar to one organization may not be familiar to another, depending on experience.

Project complexity is an organization-dependent variable, and the same project may require different levels of detail from different organizations. The *primary determinant* of complexity is organization-relevant technology. A project that is of relatively high technology for an organization requires more detailed analysis via the WBS than a project that is of relatively low technology. A project can be complex, however, even if the technology is low relative to what the organization is accustomed to; that is, it may be ill-structured, with many design options available, organizationally or interorganizationally interdependent, with many interactions required among functional disciplines, or very large. Therefore, the degree of detail found in a WBS for a given project depends on the relative level of technology required, the number of design options available, the interdependence of functional activities, and its size.

WBS and Project Management

Figure 67.15 provides an example of a WBS for a construction project. The objective of the project is to construct a television transmission tower and an associated building for housing television transmission equipment.* As a contractor for the project, we are given specifications for both the tower and building by our customer. We set out to prepare a proposal for this task that will be evaluated by the management of the television station.

As we see from the WBS, the main purpose or end item of the project (i.e., level 0 of the WBS) is provision of the TV transmission system. The primary means for providing this system are shown in level 1 of the WBS. That is, to complete the system we must provide the TV tower, the equipment building, the cable connecting the two, and a service road between the building and tower. These level 1 items are means for constructing the TV transmission system, but are also ends unto themselves for the level 2 items. For example, in order to construct the tower, we must prepare the site, erect the structure, and install the electrical system. These level 2 items are means for accomplishing level 1 ends, which themselves were means for achieving the level 0 end.

Similarly, to provide an equipment building, we must prepare the site, provide a structure, and install a fuel tank. These level 2 WBS ends are also means for constructing the structure of the equipment building. Furthermore, to provide a structure for the equipment building, we must provide a basement, main floor, roof, and interior. These level 3 WBS items are means for accomplishing the building, but also ends unto themselves.

For each level 1 WBS item, we proceed to elaborate means and ends until we arrive at means that are very familiar tasks, at which point we cease factoring the project into more detailed means. The amount of factoring done on a given end item and project therefore depends on the relative novelty associated with the project. Note that for the service road, we proceed *immediately* to final means (i.e., lay the base and grade) to achieve that end. Those two means are familiar activities to the organization and the factoring thus stops for that end item at level 1. Likewise, for the level 1 WBS item "underground cable," we simply insert one activity ("install the cable") and that ends the means–end chain for the cable.

Once we reach familiar means, we identify these as activities rather than ends, simply because they are final means, and, although our detailed planning may separate each of these activities into two or more tasks, there is no utility in identifying more detailed means. All other WBS elements, except at level 0, serve as both means and ends. Our detailed network planning begins at the level

*This example is based upon the case study "Peterson General Contractors," reproduced in R. A. Johnson, F. E. Kast, and J. E. Rosenweig, *The Theory and Management of Systems,* 3rd ed., McGraw-Hill, New York, pp. 268–273, 1973 and is included here by permission of the publisher. The case was written by Albert N. Schreiber and first appeared in A. N. Schrieber et al., *Cases in Manufacturing Management,* McGraw-Hill, New York, 1965, pp. 262–268.

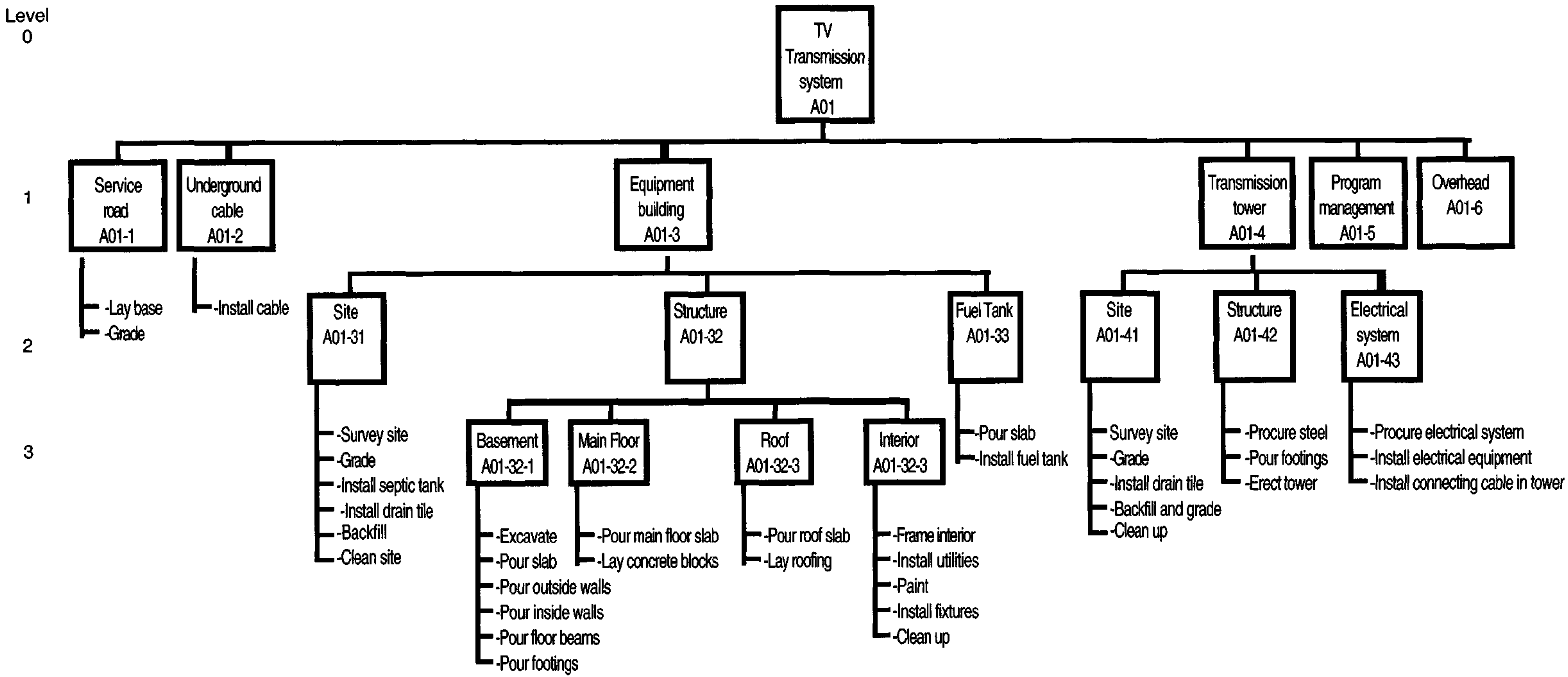


Fig. 67.15 WBS for a TV transmission system.

of the WBS, where these final means or activities are identified. Network planning thus begins at different levels of the WBS for various level 1 ends. For example, network planning will begin at level 1 for the service road, but at level 2 for the equipment building.

The elements of Fig. 67.15 that remain to be explained are the level 1 ends *project management* and *overhead.* Strictly speaking, we define our projects in terms of identifiable ends or outputs until we get down to the very last level, at which point we identify functions or activities; these latter activities are inputs rather than identifiable outputs. Because the input of project management is primarily that of planning, decision-making, and control, it cannot be traced directly to any one WBS item, but rather must be assigned directly to the project itself. We accomplish this by making it a level 1 item so as to include within the WBS framework all the resource costs associated with the project. Similarly, when deriving the WBS, we initially trace only those means that are directly related to each end item. Yet we also want the WBS to provide an accounting framework for accumulating total project costs. Therefore, we assign all indirect resources to the level 1 item called *overhead.*

Once the WBS is defined, we can assign an account-code structure to it. The purpose of the account code is to provide unique identification for each end item of the WBS to serve as the basis for the cost accumulation and reporting system of the project.

Any combination of alphabetical and numerical characters may be used; the only real requirement for the identification system is that each end item contain in its identification the account letter and number of its parent. For example, the identification assigned to the TV transmission system is A01 at level 0 of the WBS. The equipment building is identified as A01-3, indicating that its parent is the TV transmission system and that it is the third level 1 end item. The building structure is identified as A01-32, indicating that it is part of the equipment building (A01-3), which itself is a part of the TV transmission system (A01). The account-code structure proceeds down to the last end item of the WBS. Functional activities below lowest level ends of the WBS are assigned resource code numbers or letters for purposes of estimating and reporting financial expenditures by function.

67.4.3 Network Plans—Time

An Application of Network Analysis: TV Transmission System Project

We illustrate the process of network planning by constructing a network for the TV transmission system whose work breakdown structure was illustrated in Fig. 67.15. We use that WBS as the basis for network construction. From the WBS, we observe that most of the tasks to be performed are associated with either the equipment building or the transmission tower. Therefore, we shall draw one network for the building, one for the tower, and one for the service road.

The network for the building is given in Fig. 67.16. To draw the network plan for the building, it is necessary to identify the interrelationships among the lowest-level means on the WBS. We have assumed a set of interrelationships and have drawn the network accordingly. In this simple example, it is quite easy, although by no means trivial, to define optimum relationships among activities from the WBS. On more complex projects, the interrelationships must be ascertained by the planner from specialists in each functional discipline.

Notice the dashed lines that appear on this network for activities 5–6, 10–11, and 12–13. These dashed lines are called *dummy activities* and have two purposes in network analysis. First, the dummy activity is used to achieve unique numbering between parallel activities that originate at a common burst point and end at a common node. Dummy activity 5–6 is inserted for that reason. If it were

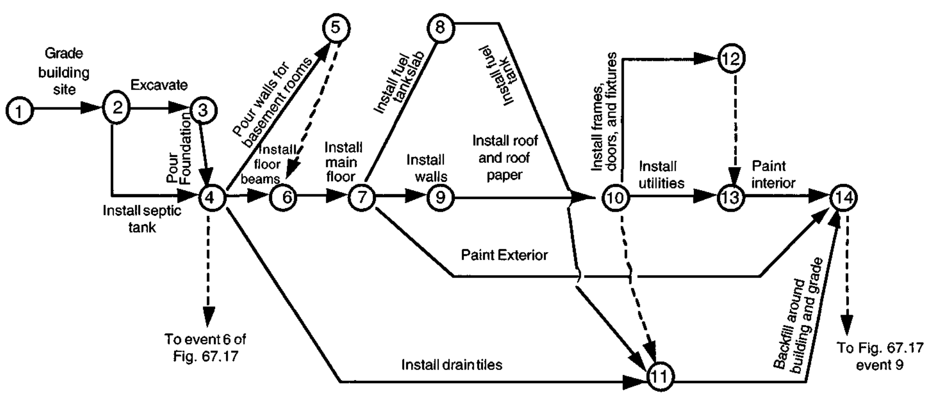


Fig. 67.16 Network for TV transmission building.

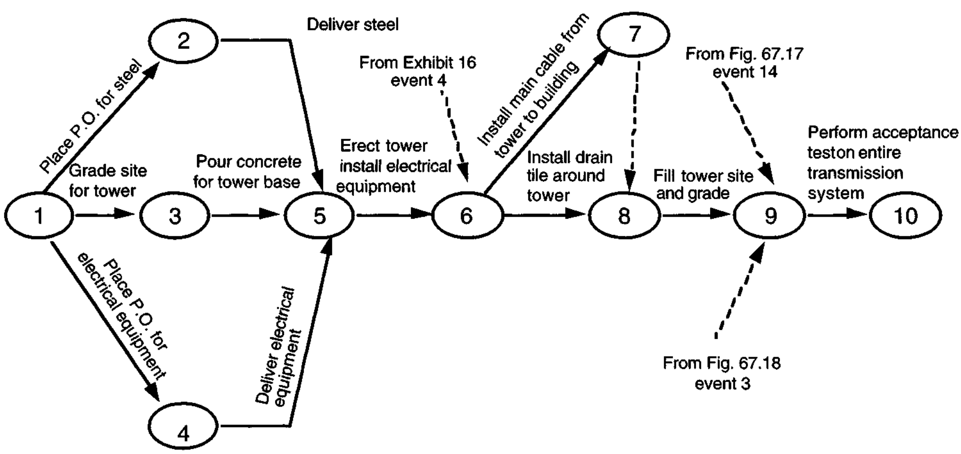


Fig. 67.17 Network for TV transmission tower.

not present, we would have two activities numbered identically (i.e., 4–6), thereby violating the uniqueness requirement. Second, the dummy activity is used to show a dependent relationship between activities where this dependency *does not consume resources.* For example, before we can fill in the foundation and grade it, the roof must be on the building and the drain tiles must be installed. Activity 10–11 depicts the dependent relationship between the fill work on the building (activity 11–14) and the installation of the roof (activity 9–10). Yet no resources are consumed by this dummy relationship. Dummy activities should be kept to a minimum in network construction, but often they are essential.

We turn now to the network for the transmission tower shown in Fig. 67.17. The transmission network is quite straightforward, with three notable exceptions. First, the *dashed lines* that flow into events 6 and 9 depict the interrelationships among the *individual networks* of the TV transmission system. Installation of the connecting cable between the tower and the building (activity 6–7) cannot begin until the tower is up (activity 5–6 of Fig. 67.17) and until the foundation of the *building* is poured (activity 3–4 of Fig. 67.16). Therefore, the dummy activity flowing into event 6 of Fig. 67.17 starts from event 4 of Fig. 67.16 and shows this physical dependency.

Second, final acceptance testing of the entire transmission system is shown on Fig. 67.17. The start of acceptance testing not only requires the tower to be complete, it also requires the completion of the building and the service road. Therefore, we have two dummy activities showing these dependencies, one from Fig. 67.16 and the other from Fig. 67.18. Figure 67.18 contains the two serial activities involved in laying the service road.

To summarize, we have constructed networks for each of the level 1 ends of the WBS. Because the connecting cable is a single simple activity, we have included it on Fig. 67.17 along with the tower. Moreover, the connecting road is a simple serial task, as shown in Fig. 67.18.

The networks constructed for this project are very simple, but realistic. Since they are quite simple, it is manageable to combine them into one integrated network for the project. An integrated network for the entire project should also contain an activity for contract negotiations with the customer. Figure 67.19 is such an integrated network, and we shall use this network as the basis for our time calculations. It is not always possible on large projects to combine individual networks into a complete project network. In those cases, we must let a computer program provide the integration of networks for us.

Network Calculations in the Integrated Network. Figure 67.19 contains time estimates and calculations for the integrated network. Time estimates are given in weeks and tenths of weeks. The entire network has an expected completion time of 24.0 weeks and a scheduled completion time of

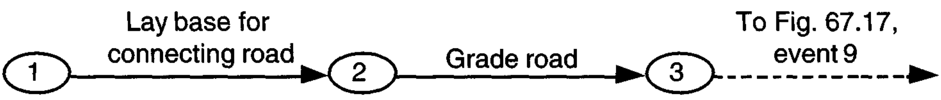


Fig. 67.18 Activities for connecting road.

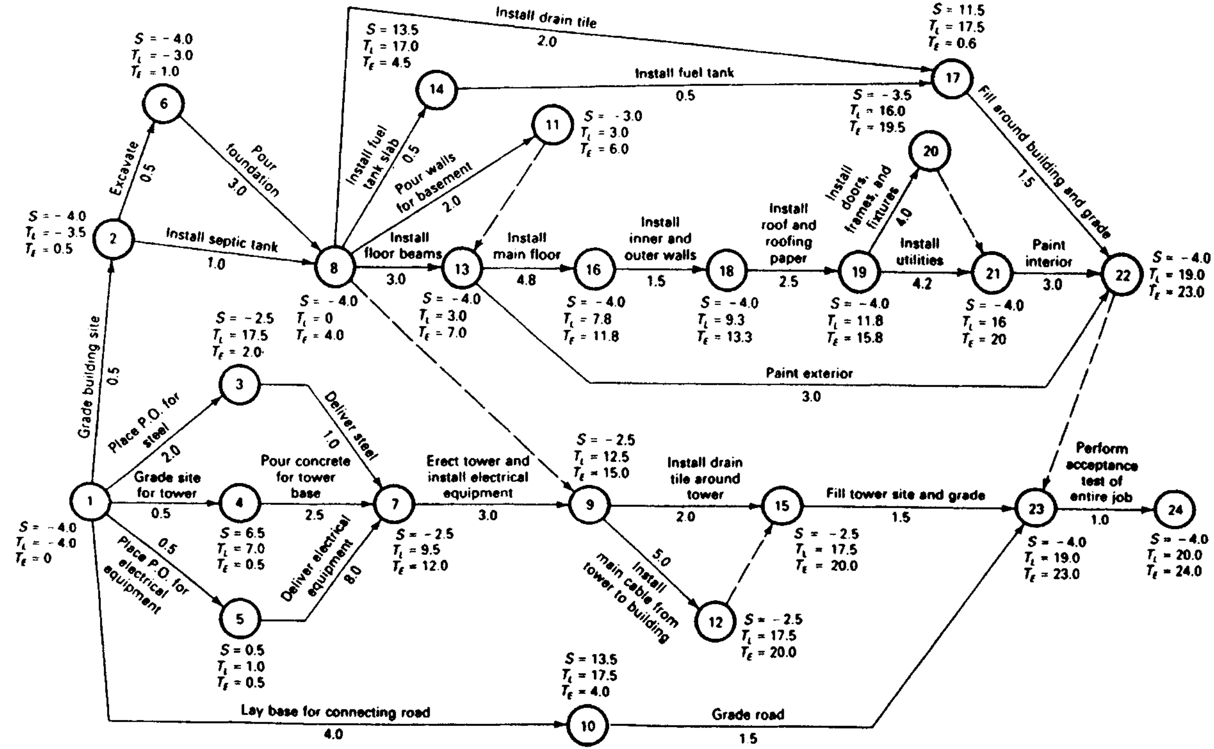


Fig. 67.19 Integrated network for TV transmission system.

20.0 weeks. The critical path has slack of –4.0 weeks and consists of activities 1–2, 2–6, 6–8, 8–13, 13–16, 16–18, 18–19, 19–21, 21–22, 22–23, and 23–24. Essentially, the critical path contains activities pertaining to the equipment building. Activity 8–11, another activity pertaining to the equipment building, has slack of –3.0 weeks and is therefore the second-most critical path.

The electrical tower is not in much better shape, either. It contains the third-most critical path of –2.5 weeks and includes activities 1–3, 3–7, 7–9, 9–12, and 12–15. You should trace through all other slack paths on the network before proceeding further.

Although we now have a network for the entire project, before we may consider this a valid plan for the TV transmission system, we must eliminate all the negative slack on the network in a nonarbitrary manner, so that the most limiting path has no less than zero slack. We turn now to alternatives that may be employed to solve the problem of an invalid plan.

Translating an Invalid Plan into a Valid One. Assuming that the time estimates provided on a network are correct, we may proceed in three ways to produce a valid plan. First, we may consider taking more risk in the way we carry out our activities by doing serial activities in parallel. Second, we may expedite certain activities in the network to save time while maintaining the optimum performance plan. If the first two procedures are impossible, we can only change the schedule date, with the concurrence of our customer or management, or redefine the project.

67.4.4 Financial-Expenditure Planning: TV Transmission System Project

Figure 67.20 is a reproduction of the WBS for the construction of the TV transmission system, but now with expenditure estimates added. Expenditures are estimated for each activity of the network and placed under the appropriate WBS item. Each WBS item has a code number to identify it uniquely. Below each WBS item is an estimate of cost, broken down by each element of cost (labor, material, and overhead). It becomes important for our reporting and evaluation procedure to have cost estimates segregated by type.

Note that the WBS includes an account code structure. Each end item in the means–end chain has a unique account number assigned to it. Each means is linked to its parent end item by this hierarchical numbering system. The code structure is very useful in the financial estimation phase of the project control process.

For example, the account code number for the overall project is A01 (i.e., level "0" of the WBS). Each level 1 WBS item carries the number of its end (i.e., A01) plus a unique suffix to identify it. For example, the equipment building number is A01-3. Each level 2 item carries the number of its parent plus a suffix to uniquely identify it. The building structure is numbered A01-3-2 to signify that it belongs to the overall system (A01) and to the equipment building A01-3.

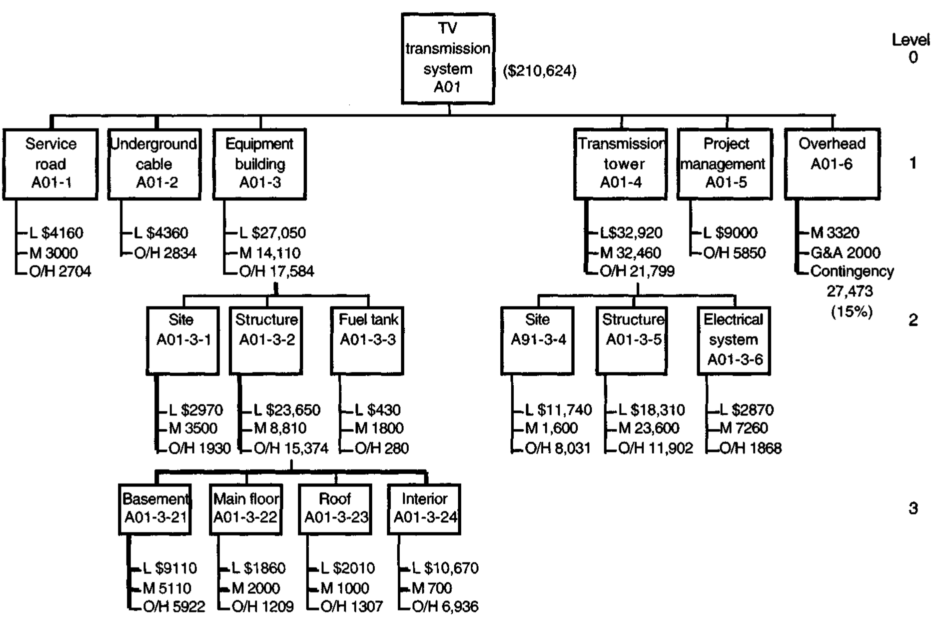


Fig. 67.20 WBS for TV transmission system.

The WBS of Exhibit 20 has three levels. To estimate standard costs for each end item of the WBS, we estimate each of the lowest-level end items and accumulate the standard costs up the WBS.

From the network of the TV system, we estimate direct labor and material cost for each of the lowest-level end items of the WBS. Since this is a relatively small project, each lowest-level end item is equal to one work package, and we develop *planned value of work* estimates for each of the lowest-level end items. We identify direct labor and direct material costs separately under each end item.

The standard overhead rate for this organization is 65% of labor costs. Labor cost is therefore the activity criterion. The organization has determined that indirect expenditures vary more directly with labor costs than with any other input or output variable. The overhead rate is thus computed by estimating overhead expenditures over the accounting period (normally a year) and dividing these expenditures by the expected or normal volume of labor costs for that same period.

Once we have arrived at the overhead rate, we simply apply it at each lowest-level end item to the standard assigned to the variable that serves as the activity criterion. This gives us the standard overhead charge for that end item. We then sum the three elements of cost to arrive at standard costs for an end item.

Since we can relate a lowest-level end item to the network, we shall be in a position in the reporting phase to collect actual costs for work performed and compare them to the planned value of work performed. Finally, we sum standard costs for each end item to its parent to find successively higher levels of project costs until we arrive at the standard cost for the entire system (i.e., A01 on the WBS).

Note that there are costs for project management and certain other overhead items that we choose not to allocate to project end items, instead identifying these separately at level 1 of the WBS. Of course, they too become part of our total estimated costs for the project. The estimated costs for the project may also be displayed by month, as in Fig. 67.21. Figure 67.21 becomes a control document. It does not contain profit or contingency, thus displaying a total cost $44,579 lower than the costs appearing on the WBS in Fig. 67.20.

The work package, which is a series of related activities, because it connects the WBS, the network, and the cost-accounting system for a meaningful segment of work, is the basic instrument for integrating the time and cost variables of a project. It is the lowest level of detail at which it is feasible to devise a combined measure of performance for time and cost.

The combined measure of performance is ordinarily called *the planned value of work* and it is arrived at simply by estimating the *budgeted value* of work represented on the network for each work package. Each work package thus contains estimates of its planned value, so that any major part of the work package is accorded a corresponding planned value.

Once work progresses, we collect data on actual expenditures and progress and assign *actual cost for work actually accomplished* for each work package. We then compare the *planned value for work actually accomplished* with the *actual cost for work accomplished* and compute the variance. The variance thus represents a measure of cost performance versus plan for the work actually accomplished. It integrates expenditures with schedule performance, thus achieving the joint measure of performance we seek. We shall discuss this integrated reporting measure further later in this chapter.

Months (Days) Worked

Element of Cost	1 (1-22)	2 (22-44)	3 (44-66)	4 (66-88)	5 (88-110)	6 (110-132)	7 (132-154)	8 (154-176)	Total
Labor	$17,200	$ 8,570	$5,220	$2,660	$15,100	$ 3,600	$ 14,110	$ 2,300	$ 68, 760
Material Expenditures	30,860	21,730							$52,590
Applied O/H (65% of labor)	11,180	5,571	3,393	1,729	9,815	2,340	9,172	1,495	$44,695
Project Total Cost	59,240	35,871	8,613	4,389	24,915	5.940	23,282	3,795	$166,045
Cumulative Total Cost	$59,240	$95,111	$103,724	$108,113	$133,028	$138,968	$162,250	$166,045	

Fig. 67.21 Financial expenditure plan according to expected completion dates.

67.4.5 Scheduling Resources

Project plans represented by networks and financial plans provide functional management with the requirements, resources, and priorities for their function on each of the organization's projects. Although network plans provide a possible schedule for accomplishing the work, this schedule is not always practical or feasible when all other requirements placed on the function are considered. There are six specific requirements excluded during the planning process that must be considered during the resource allocation process. They are as follows:

1. Sufficient resources to perform each activity in an optimum manner is assumed to be available when formulating and optimizing plans. Limited availability of resources and the competition among projects for the same resources must be taken into account during the resource-allocation process.
2. The pattern of resource demands from all of the project plans must be considered not only in the light of resources available but also in terms of the distribution of demand placed on resources over time. Functional management cannot be expected to increase and reduce functional resource continuously in light of the fluctuating demands of each project. Functional resources levels are determined based on long-term organizational demands and their use must be relatively even from one period to the next.
3. Common facilities (e.g., computer time and testing equipment) are often required simultaneously by activities of the same project or by activities of different projects. The allocation process must resolve these conflicts.
4. Cash flow requirements of the projects are not always feasible for the organization, and these limitations enter into the allocation function.
5. State work laws and regulations must be observed in allocation decisions when overtime is being considered.
6. The nature of the contract negotiated between contractor and customer with regard to the relative value of various projects to the organization, as well as the long-term objectives of the organization, affect the relative priority that should be accorded various projects by the organization. This is another consideration of the resource-allocation process.

Not only must we recognize scheduling as a distinct activity in the project-control process separate from, yet related to, planning, but we must also establish different time horizons for these two activities. Project planning must be carried out for the entire duration of the project. Scheduling, on the other hand, ordinarily may be done profitably only on a short-term time horizon.

Scheduling requires commitment of resources on the part of functional management to specific tasks of the many projects of the organization. As the network relationships indicate, however, activities of one functional organization are dependent on the completion of activities of other functional organizations. Because of the dynamic, constantly changing nature of complex projects, we cannot expect network relationships and time estimates to be very precise. Expected start and completion times of activities become more tenuous the longer the elapsed time from the present. Therefore, functional organizations cannot establish realistic long-term schedules for carrying out the work of multiple projects. It is usually futile to allocate resources to specific jobs unless they are to be performed in the near term. More accurate scheduling can be done for these near-term activities, since most of the activities that limit their start are either in progress or complete.

Start dates for activities that are scheduled by the functional organizations must find their way back to appropriate project plans. Scheduled start dates are *superimposed* on network calculations, and they supersede expected start dates in calculation of the network so long as they are equal to or greater than expected start dates. Scheduled start dates that are earlier than expected start dates are invalid. Project office personnel must check the consistency of functional schedules and approve their implications. The portion of a project plan that has been scheduled is called a *scheduled plan.*

Although distant activities cannot be scheduled, it is important to preserve a valid plan for distant work, since the time estimates and interrelationships of the entire plan determine the time requirements (required dates) of work that can be scheduled.

To summarize this section, we may say that resource allocation or scheduling is a function with different purposes than planning. A network plan cannot ordinarily be used as a schedule for a project, yet it must serve as the basis for the schedule. Moreover, once activities are scheduled, these data must be incorporated into network plans. Thus, there is communication between these two important functions. If the plan alone is used as a schedule for performing the work, with slack used without considering other activities and competing projects, the ability to optimize performance in the organization is restricted and the value of the project-control system is lessened.

The resource-allocation process consists of three distinct but interrelated tasks: *resource loading*, *resource leveling*, and *constrained resource scheduling.* Resource loading is concerned with deriving the total demands of all projects placed on the resources of a function during a specified period of

Projects/ Functions	1	2	3	4	5	Total Functional Hours
A	20	40	8	5	0	73
B	30	30	15	0	0	75
C	25	25	20	8	20	98
D	10	15	20	14	30	89
E	40	10	12	10	0	72
Total Project Hours	125	120	75	37	50	407

Fig. 67.22 Resource loading in matrix format.

time. Resource leveling attempts to "smooth out" the demands to eliminate major peaks and troughs. Constrained resource scheduling is concerned with achieving all demands of the projects of an organization within the resource constraints of the function at minimum disruption to the plans of each of the organization's projects.

Resource Loading

To understand the resource-loading process, it is convenient to view the problem in matrix form. The various projects of an organization place demands on resources during a particular period of time, and the functional organizations supply these resources. A matrix illustrating this process appears in Fig. 67.22. The matrix represents the total demands placed on each of five functions by each project for a 10-week period of time. These demands, however, are not time-phased in this Figure. The resource demands in the matrix are taken from the work packages that are expected to be performed during the scheduling period.

Information on demands placed on each functional group during the scheduling horizon is only part of the information required in the resource-loading process. Slack information from each of the project plans is also required.

Figure 67.23 is an example of a report for one function, engineering, for one project for a 10-week period. This information is derived from project plans. The activities represented on the report have start dates, expected completion dates, required dates, and slack calculations.

Loading information from work packages is combined with calculations of slack from project plans into the resource-loading report for one functional organization. Figure 67.24 presents an example of a time-phased loading plan based on expected start and completion times for each of the activities. Where positive or negative slack exists, it is indicated by an extension of each bar to its right (for positive slack) or left (for negative slack—none shown on Fig. 67.24). Within each bar we have placed the number of persons per week required to achieve each task and have summed the total demands placed on the function vertically by week. The row on the bottom of the chart therefore contains an estimate of the total demands in terms of person-weeks of effort placed on the function of design engineering by all projects. Fig. 67.25 presents the loading plan graphically.

From Fig. 67.25, we note that there is an uneven distribution of demand for design resources over the 10-week period, with very high demands occurring in weeks 6–7 and 7–8. Even if resources are in good supply in the design organization, it is usually undesirable to have these large variations in

Function: Engineering **Project: XXX** **Responsibility:** **John Smith-1997**						
Preceding/Succeeding Event Numbers	Activity	Time Estimate	Start Date	Expected Completion Date	Required Completion Date	Slack
001-002	Prepare Detail Design—Component 101	2.0	01/01	01/15	01/29	2.0
011-012	Prepare Detail Design—Component 105	4.0	01/15	02/15	02/15	0.0
021-022	Prepare Detail Design—Component 208	3.0	02/01	02/22	02/15	-1.0
031-032	Prepare Detail Design—Component 304	1.5	02/01	02/11	02/04	-1.0
051-052	Prepare Detail Design—Component 508	2.5	02/15	03/03	03/01	-0.4

Fig. 67.23 Planned activities of functional organization.

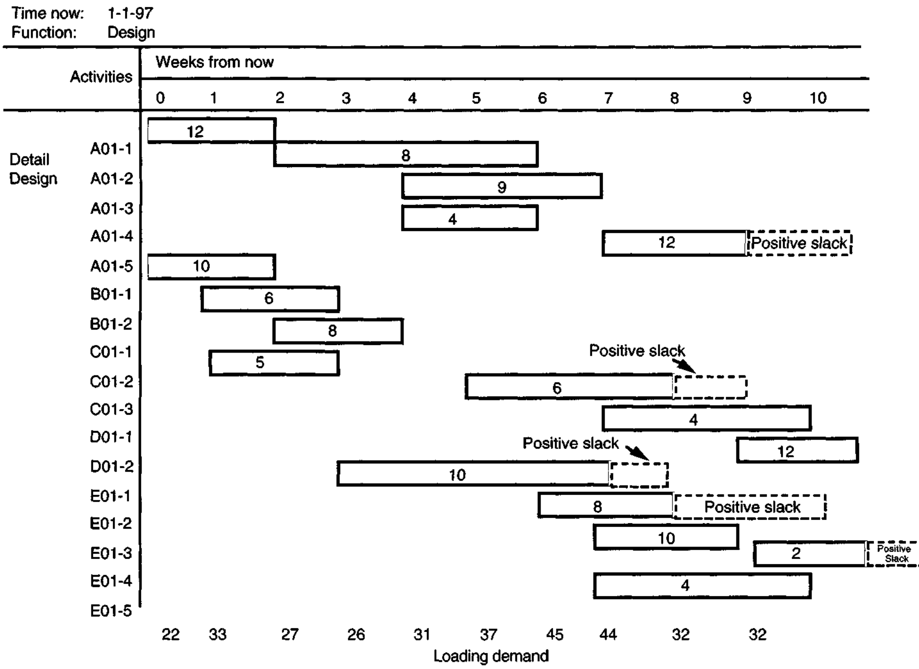


Fig. 67.24 Time-phased human resource loading plan.

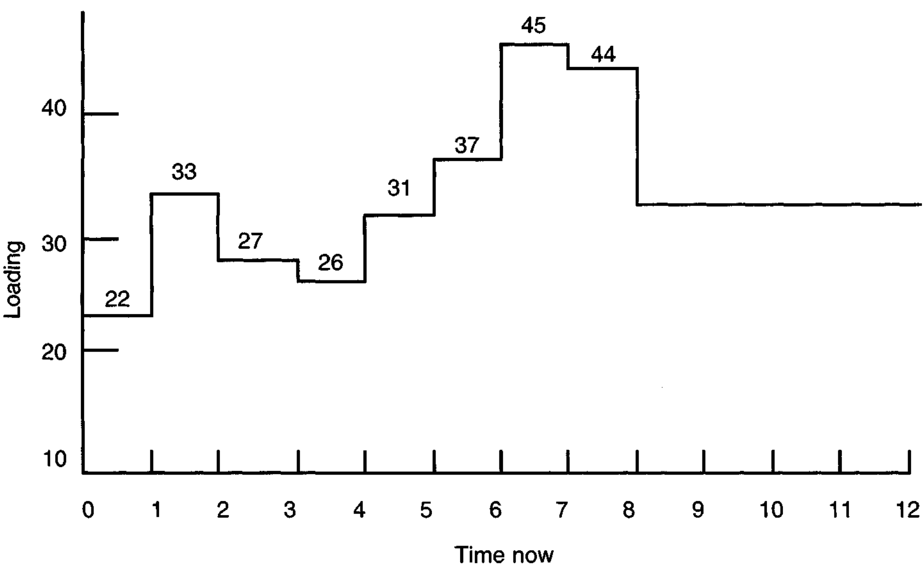


Fig. 67.25 Profile of demands for resources.

the demand for resources. The *resource-leveling process* attempts to remedy this situation by leveling or smoothing resource demands within the constraints of required dates for the various activities.

Resource Leveling

The resource-leveling process begins with the resource-loading and slack calculations of Fig. 67.24 and the resource profile of Fig. 67.25. It proceeds to *level* the demands for resources *without* exceeding the required dates of projects. The process is constrained by its leveling objectives and not by available resources.

By the use of slack calculations, some start times of activities may be adjusted to begin later than their earliest expected start date, thus shifting the demand for resources to a later point in time, *without* exceeding the original expected completion date of the network. Therefore, the resource-leveling process requires us to adjust performance times of activities according to slack calculations to produce a pattern of demand for resources that is as stable as possible over the scheduling horizon.

The resource requirements of the valid plan are taken as a beginning point for resource leveling. Required completion dates are treated as constraints so that we maintain valid plans. Adjustments are made by each functional manager; these adjustments are coordinated with personnel assigned to the various project-management offices to ensure that each functional organization does not frustrate the schedules of the other. That is, the use of slack by the various functions must be coordinated by the various project offices.

Free slack (or float), which we define to be that part of activity slack that, if used, does not affect slack calculations forward of the activity in the network, may be used immediately without approval of the project office, since its use cannot affect any other activity in the project. Normal slack, however, is identified with a path and although we may use it during resource leveling, its use must be coordinated with project office personnel whose project is affected. Coordination is necessary since only one activity on a path may use its positive slack; if all functions represented by activities on a single path use the slack, the combined network calculations would produce a negative slack path!

The resource-leveling function may be carried out manually unless the networks are large and involve multiple resources. Computer programs are available to assist in carrying out the resource-leveling process for complex networks.

Resource leveling for our sample projects results in the revised loading plan of Fig. 67.26 and the resource profile of Fig. 67.27. Note that in the leveling process we were able to reduce peak

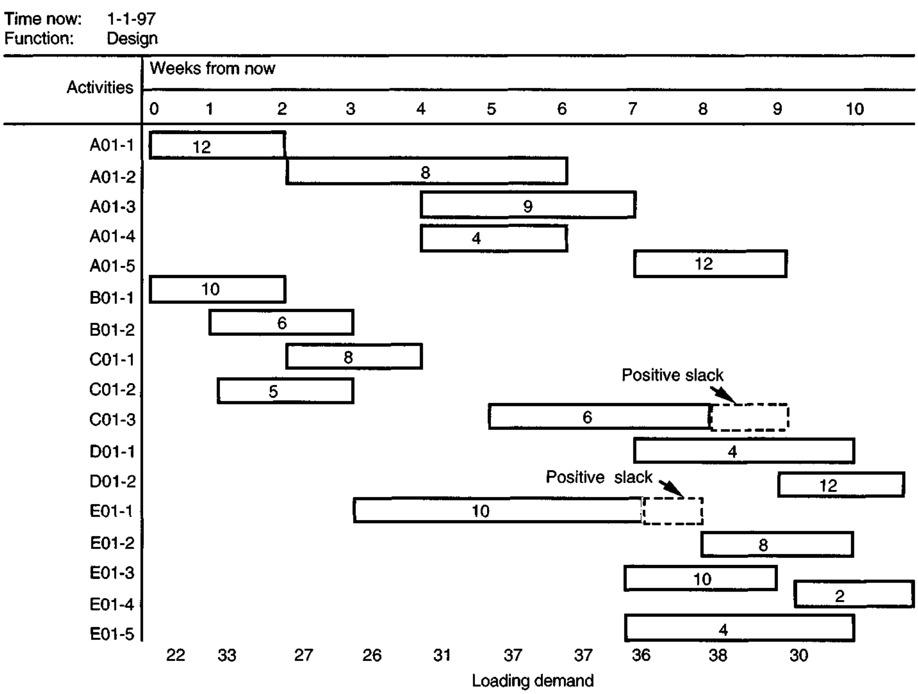


Fig. 67.26 Resource-leveled plan.

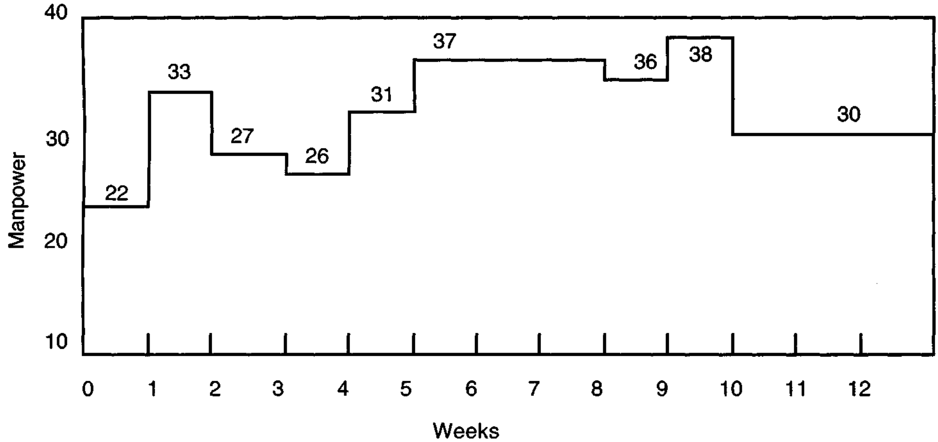


Fig. 67.27 Revised profile of demands for resources.

demands of weeks 6–7 and 7–8 significantly. This was accomplished by the selective use of positive slack that was available on the project. Assuming the use of slack meets the approval of the proper project office personnel, the leveling procedure results in a definite improvement in the distribution of resources of the design organization. The resource profile produced by the resource-leveling procedure, however, may not be feasible in light of known resource levels. The next problem, therefore, involves scheduling all these design tasks within the limits of available engineers. This is the task of scheduling subject to resource constraints to which we turn now.

Resource Scheduling Subject to Resource Constraints

If the resource-leveling process produces a loading profile within the resource limitations of the function, all is well. If, however, the loading demands of the leveling process produce resource requirements that exceed resource availability, including the use of overtime, then we must relax schedules until they "fit" within resource limits. This relaxation process must be done in such a way as to minimize the extensions required to the critical path while maintaining a reasonably smooth distribution of demand for resources.

When the resource-leveling procedure does not produce a feasible schedule under otherwise optimal planning conditions, we are forced to increase the duration of schedules of at least some projects of the organization. To determine which activities should be prolonged, we require a priority system. Two types of systems exist: *optimal* procedures and *rule-of-thumb* or *heuristic* procedures. We examine each category in turn.

A number of optimal procedures exist for scheduling resources, including linear programming. Uncertainty is a fundamental difficulty with all optimization techniques applied to resource scheduling. There is a good deal of uncertainty in complex projects concerning even the best estimates of time, relationships, and resources for activities. To devise optimal schedules, after elaborate calculations, based on these uncertain estimates seems not to be worth the cost. Less optimal rule-of-thumb procedures would seem to be good enough in most cases and worth the cost of the exercise. We now turn to these so-called *heuristic* procedures.

Heuristic Scheduling Procedures

Heuristic procedures are rules of thumb for solving problems; they are used to develop satisfactory but usually not optimal schedules. Such procedures are widely employed to solve the constrained resource scheduling problem. Starting from the optimum plan, these procedures lead us to schedule activities based on certain rules in order to produce good resource-feasible schedules.

A heuristic procedure for scheduling within resource constraints must contain decision rules for extending activities so that total resource requirements are within resource constraints. There are two common decision rules:

1. Accord priorities to activities based on their required completion dates, with activities having the earliest required completion dates scheduled ahead of those with later required completion dates.
2. Rank activities in order of duration and perform activities with the shortest duration first.

These two rules of thumb are given as examples of procedures that may be used to solve the constrained scheduling problem, given a leveled loading plan. All heuristic procedures proceed to extend activities that cannot be accommodated by available levels of resources through the use of one of these rules. A heuristic procedure must also have secondary rules for breaking ties. For example, if two activities have identical required dates yet cannot be performed simultaneously because of resource constraints, we might decide to perform the one with the shortest duration first.

It is important to realize that these rules of thumb are not likely to produce optimal schedules. They are designed to produce satisfactory feasible schedules. When placed in the context of the uncertainties found in organizations engaged in complex projects, however, rules of thumb such as these are operational and flexible enough to respond to the inevitable changes brought about by these uncertainties.

We should note that although we have described the resource allocation process as three distinct but interrelated tasks, in practice, they are often performed informally and simultaneously, depending on the magnitude of the task and the sophistication of the project-control process.

67.4.6 The Budget Process

A close parallel exists in the relationship between expenditure planning and budgeting to the relationship we described between network planning and resource scheduling. The resource-scheduling process begins with the activities, time requirements, and calculations of the network and proceeds to load resources, smooth resources, and construct schedules that are resource-feasible for a short period of time into the future. The portion of a network plan that has been scheduled for performance by functional groups is called a *scheduled plan.*

Similarly, the budgeting process begins with plans established during the financial planning process and proceeds to authorize expenditure limits within which, *on balance,* budgets are expected to adhere. The budget for a work package, however, is likely to differ in some important aspects from the financial plan, since the authorized work package must reflect decisions made in the resource-allocation process. The portion of the financial expenditure plan for which we have a budget is called a *budgeted plan.*

Work Package and Operating Budgets

Projects require an operating budget. For functional organizations engaged in complex projects, however, it is almost impossible to prepare an annual operating budget with any degree of confidence that it will be followed closely. Yet each organizational unit must perform resource and expenditure planning over a longer horizon than that which it can forecast perfectly.

This apparent budgeting dilemma is resolved by requiring both work package and operating budgets. Work package budgets, covering a short period of time, serve as work-authorization documents, whereas approved operating budgets serve to guide decisions regarding resource levels in each of the functional departments.

Financial data on work packages prepared during the expenditure planning process are far from ready to serve as budgets for the project. These financial plans were derived from estimates of network activities. As we saw previously, network plans ordinarily cannot be converted directly into schedules, but rather must be considered in light of available resources and other competing demands. Therefore, the financial plans of a given work package cannot be converted into budgets until the activities included in the work package have been scheduled, for only then do we know precisely when activities will be done and by whom and what resources will be used. Only a small portion of the financial plan is eligible to serve as a budget, for only a small portion of the network plan upon which the expenditure plan is based has been scheduled. The budget for the portion of the network plan that has been scheduled is negotiated between project and functional personnel. The approved budget then serves as the document that authorizes functional work.

The Budget as an Authorization Document. We have seen that to achieve scale economies and coordination, the matrix structure causes us to violate the classical principle of *unity of command.* The stresses produced by the dual sources of command to which functional personnel must respond are nowhere potentially more divisive than in the budgeting and authorization process. This process, however, if performed correctly also possess opportunities to enhance identification with project goals, to improve performance, and to reduce or eliminate these natural tensions caused by dual lines of command.

Since the management function of directing project work formally may lie with functional managers under the matrix structure, the project manager should use the budget and related authorizing documents to exert "purse-string" authority over functional performance.

Once the scheduling is prepared for functional work, the budget implications may be derived by applying rates for each cost element as established in the project cost-accounting system. The schedule for functional work and its supporting budget serve as authorizing documents for functional work. By reviewing and approving the schedules and budgets of these work packages, the project manager begins to assert control over his or her project. Thus, a major portion of a project manager's time is spent negotiating budgets with functional managers in light of original financial planning for the work, current schedules, past performance by the various functions, and overall project status.

Project office personnel should ask the following questions regarding proposed work package budgets:

- Does the schedule as presented by the functional groups validate our project plans?
- Will the schedule work meet performance and quality specifications?
- Is the budget for the work consistent with planning estimates?

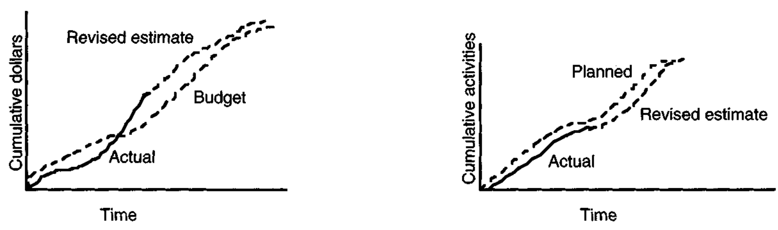
If each of these questions is answered in the affirmative, the project manager simply approves the budget and authorizes performance. He or she may authorize performance for the entire scheduling horizon (10 weeks in our examples) or for the duration of the work package. The authorization period is controlled by specifying the time period during which the project manager will accept charges against the account number assigned to a given work package.

Planned Value of Work. The characteristics of complex projects require that we integrate time and expenditure plans into a measure of *planned value of work performed.* Once a schedule and budget are prepared and approved, *planned value* may be established for each work package, or it may be decided to integrate expenditure and time plans at a level somewhat higher on the WBS. The tightest control is achieved when planned values are established at the work package level.

If the integration is done at the work package level, the planned value of work becomes the approved budget for the work package. Later in the reporting process, actual costs for work performed on a work package can be compared with planned value for work to monitor in an integrated way time and cost performance.

The authorization document is a work package approved by the project manager or by his or her representative. It should contain detailed information on time, cost, planned value, and expected performance on that segment of work. When approved by both project and functional management, it becomes the agreement, or performance contract, between project and functional personnel. Figure 67.28 provides an illustration of an authorizing document.

Figure 67.28 contains a summary description of the work embodied in the work package, a milestone chart indicating scheduled completion dates for work package activities, a time-phased financial expenditure plan, and a time-phased work plan. Finally, it contains planned value of work calculations for major milestones.



Function	Schedule
Design	1▼ 2▼
Drafting	3▼ 4▼
Reliability	5▼ 7▼
Manufacturing	6▼
Test	8▼
	Calendar weeks

Planning value of work scheduled

Milestones:

1. Complete preliminary design
2. Complete final design
3. Prepare preliminary drawings
4. Prepare final detail drawings
5. Reliability summary
6. Manufacture
7. Reliability summary
8. Test

Work package description: The purpose of this task is to design and fabricate air inlet value according to specification xxx. WBS No. xxx-xxx-xxx

Fig. 67.28 Sample work package authorization document.

If the process leading to the issuance of the authorizing document is properly organized, the standards established should induce sufficient motivation on the part of functional personnel to perform the task and achieve or exceed the standards established.

The Budget Procedure. Operating budgets are ordinarily prepared for each project and functional organization on an annual basis. Each project manager prepares an operating budget for each period, and the budget normally represents a portion of the overall budget for the entire project. Each project budget contains an estimate of revenue and expenses. Expenses are ordinarily derived from a combination of approved work package budgets and project expenditure plans for the period, and normally include some funds for contingency. Estimating annual revenue for projects that are expected to extend over many budgeting periods is a difficult problem and tied to specific contract provisions.

Operating budgets are also prepared for each functional group for the budget period. If these functional budgets are tight and challenging, we must expect many functions to require some contingency funds for inevitable overexpenditures. These funds may be provided either through an appeal process to project managers, and a corresponding revision to the operating budget, or through a partial allocation of contingency funds from project budgets to functional organizations during the expenditure planning process. The latter procedure is likely to lead to goal-congruent behavior if functional organizations are treated as profits centers. The former procedure is likely to be most effective if functional organizations are treated as cost centers, which is the typical responsibility center designation for these organizational units.

Operating budgets for functional disciplines are prepared by summing approved work package budgets pertaining to a function with planned expenditures derived from approved project expenditure plans for the portion of the budget period not covered by approved work packages.

Contingency funds are required in these operating budgets to allow for some overexpenditures that are expected with tight budgets as well as unanticipated but inevitable differences that occur between financial expenditure plans and approved work package plans. That is, annual operating budgets for each function must be approved based largely on expenditure plans of the organization. Later, approved costs of work packages usually will deviate from the costs included in the original operating budget because of changes that occur between the planning process and the resource-allocation process.

If differences between approved work packages and operating budgets are large, revisions are called for in operating budgets; if differences are small, they should be absorbed into a contingency account, which itself may be treated as an overhead account, along with all other nonproject work. The functional department overhead account should also include idle time, company-sponsored research and development, proposal effort, indirect functional supplies, and functional supervision.

Functional Overhead Budgets. Functional overhead budgets normally contain estimates for all functional expenditures that cannot be traced directly to a funded project. Functional organizations are normally held responsible for performance regarding these overhead budgets. Under these circumstances, functional managers will attempt to keep their personnel employed on either a contractual project or an approved company-funded project, such as a proposal or a research project. Otherwise, the time of functional personnel must be charged to a special account called "idle time," and although some charges are expected to this account because of resource-allocation problems and because of normal transitions from one project to another that often involve delays, these charges must be kept to a minimum for the functional manager to achieve good performance regarding his or her overhead budget.

Project managers, on the other hand, seek to remove functional resources from their project as quickly as possible, since the performance of these managers is often evaluated based on profit. Functional managers must be able to use these personnel on other projects *for the organization as a whole* to achieve the cost reduction that is attributed to the project office. If the organization cannot use personnel so released, their time must be charged to idle time, which may cause functional managers to overexpend their overhead budgets! If functional overhead budgets are in jeopardy, the temptation is always present to mischarge functional time to contracts that appear to be able to absorb such charges and to prolong existing problem work longer than necessary.

Because many organizations treat their level of functional resources as essentially fixed during the short term, an unplanned underexpenditure on a project ordinary shifts an equivalent amount of costs somewhere else in the organization and does not result in a comparable organizational saving *unless* these resources may be absorbed profitably on another contract or on approved internally funded project.

These facts of organizational life leads us to place a premium upon planning and flexibility on the part of functional managers. Functional planning must always include provision for contingencies, whether this takes the form of preplanned effort on internally approved projects or plans to shift resources to new projects if these resources are released prematurely.

If this kind of contingency planning is not done in functional disciplines, pressures will build to mischarge contracts, overrun overhead budgets, and adjust the level of personnel in the organization at an undesirable rate.

Moreover, it is a mistake to place too much emphasis on performance regarding overhead budgets in the evaluation of functional managers to the exclusion of their performance regarding cost, schedule, and quality of all projects that are supported by the function. In addition, the quality of planning for the use of functional resources should play an important role in their performance evaluation.

67.4.7 Systems of Reporting for Project Control

To put the general requirement of a reporting system for complex projects into perspective, it is necessary to remember that we are describing a system that replaces the cost-accounting system in the management control process. The project cost-accounting system, however, *does have similarities* with conventional cost-accounting systems (e.g., account code structure, standards, variances, and overhead allocations), as we have seen. Therefore, when it comes to designing project-reporting systems, it is useful to begin by reviewing the reporting system established in conventional cost accounting for each element of cost. It turns out that each of the variances used in conventional cost accounting may be used in project cost accounting, but they must be supplemented with combined cost and schedule variances.

The labor variances of conventional cost accounting are subdivided into time and rate variances. The time variance is found for a task as follows:

$$(\text{standard hours} - \text{actual hours}) \times \text{standard rate} = \text{time variance} \tag{67.1}$$

The rate variance for labor is found by

$$(\text{standard rate} - \text{actual rate}) \times \text{actual hours} = \text{rate variance} \tag{67.2}$$

The total labor variance for a task is

$$\text{standard labor cost} - \text{actual labor cost} = \text{total labor variance} \tag{67.3}$$

Material variances are similarly subdivided into quantity and price variances. The quantity variance is computed as follows:

$$(\text{standard quantity} - \text{actual quantity}) \times \text{standard price} = \text{quantity variance} \tag{67.4}$$

The price variance is given by

$$(\text{standard price} - \text{actual price}) \times \text{actual quantity} = \text{price variance} \tag{67.5}$$

The total material variance is

$$\text{standard material cost} - \text{actual material cost} = \text{total material variance} \tag{67.6}$$

We omit the overhead variances, since our project-reporting system ought to focus primarily upon controllable project costs.

Now the difference between the requirements for project reporting and conventional cost reporting systems develops because the labor and material variances are only *cost* or *spending variances.* They essentially assume that the scheduled work was completed in the process of spending funds for labor and materials. This is a realistic assumption in most manufacturing operations. Not so, however, in the management of complex projects.

For any WBS item, we are interested in the relationship between *planned value of work* for a given time period and *actual cost of work* for the same time period. This will tell us our total variance for the task and we, by the computation of more detailed variances, seek to trace its causes. There are five potential causes for any total variance:

1. We did more or less work than scheduled.
2. We used more or less labor than planned for the actual work we did.
3. We paid more or less than planned for the actual labor used.
4. We used more material than planned for the work we accomplished.
5. We paid more or less than planned for the material we actually used.

The portion of the total variance attributable to number 1 is called the *schedule variance,* and the portion attributable to numbers 2–5 is called the *spending variance.* Therefore, the total variance for a given task or end item of a project is budgeted value of work planned − actual cost of work accomplished = total variance (67.7)

The schedule variance is given by

budgeted value of work planned − budgeted value of work accomplished = schedule variance (67.8)

The spending variance is

budgeted value of work accomplished − actual cost of work accomplished = spending variance (67.9)

The spending variance is then subdivided into labor and material variances according to Eqs. (67.3) and (67.6). Labor and material variances may be subdivided further into rate and quantity variances according to Eqs. (67.1), (67.2), (67.4), and (67.5).

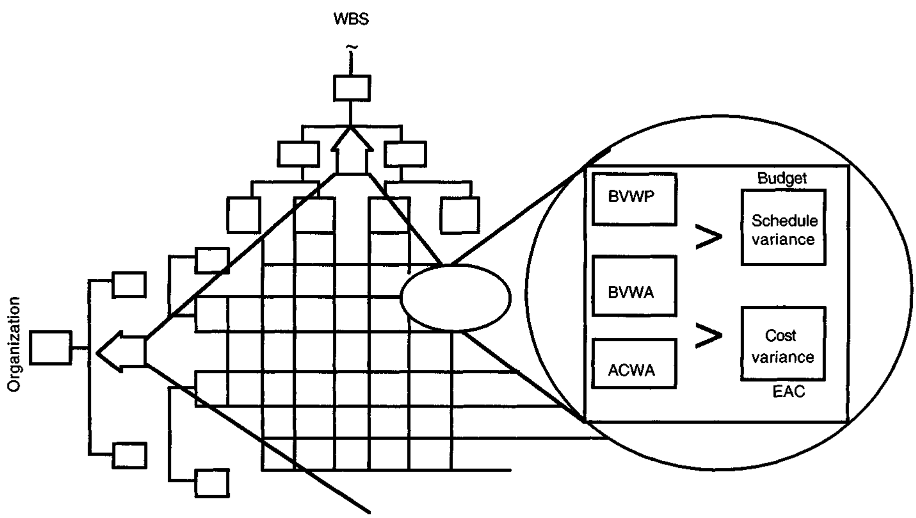
These nine variances, 67.1–67.9 may be computed for each level of the WBS and for each functional organization at regular intervals throughout the life of a project. The total variances for a WBS end item tell the responsible manager whether there is a problem or not regarding cost and schedule performance. If a problem exists, he or she can request more detailed reporting information for the next level of the WBS and find exactly where the problem is and whether the problem is concerned with schedule slippage or with a labor or material spending variance.

Note the only variance that is new is the schedule variance. Each of the other variances appears in conventional cost-accounting systems. The schedule variance requires for its computation data on planned and actual schedule performance together with normal cost data for each level of the WBS. The fact that there is only one new variance required should dispel any mystery surrounding the schedule and cost-reporting requirements for complex projects.

Conceptually, the time-and-cost reporting system for complex projects may be represented by Fig. 67.29. We should be capable of calculating a schedule variance and a cost variance for any level of the WBS. We should be able to divide the cost variance into its labor and material elements. We should be able to trace the schedule variance to a scheduled plan.

The reporting system should also contain the capability to provide information for each functional organization that is performing work on the project by WBS end item. This information should follow the same format as that for the project.

These, then, are the broad outlines that the formal reporting system should take with the recognition that the system should be flexible and adaptable to each organization.



The variance terms in the diagram are defined as follows:
BVWP---budget value of work planned; BVWA---budget value of work accomplished;
ACWA---actual cost of work accomplished; EAC---estimate of cost at completion.

Fig. 67.29 Integrated time-cost reporting system.

Let us look at an example of an application of our variance system. Let us assume that we are considering a work package for the structure (A01-3-2) of our TV transmission building. Moreover, let us assume we placed the material orders at the estimated price and that we have chosen not to include overhead in our project control reports, since the project manager has little or no control over it. Therefore, our primary control variable is the estimated $23,650 of labor costs for this work package.

Approximately six weeks into the project, we have an integrated progress chart drawn up for us, as shown in Fig. 67.30. The chart shows that work on the structure is currently three weeks ahead of schedule, yet that is not the whole story. The schedule variance is positive, we have done more in the first six weeks than originally planned (i.e., BVWA > BVWP). Yet we have spent more than budgeted for the work accomplished (i.e., ACWA > BVWA). Projecting these trends to completion, we will spend approximately $2,000 more than estimated but we will finish three weeks early. Our conclusion at first look might be that the schedule gain was accomplished by spending more labor resources, and further investigation might show that to be true. Nevertheless, unless there are some changes made, the work package will overrun by approximately $2,000 at completion. The integrated report gives us a rather complete picture. It is much clearer than independent budget versus actual expenditure and schedule progress reports.

Reporting Delays and Bias

There always must be some delay between actual project progress and problems and their reporting, since the reporting process consumes time. All project status must be ascertained from the performing organizations. These data then must be processed. After processing, these reports must be analyzed to ensure that the processing was done correctly and to assess progress and problems. It is not unusual for this processing and analysis work to consume two weeks or more on a complex project although it could occur daily.

Moreover, the subsequent meetings and recommendations for action may take still another week or two. When action is finally taken, it may be to remedy a problem that existed a month ago! To further complicate the reporting problem, bias may creep into the reports.

If functional supervision is evaluated based on its rate of progress alone, then we should expect bias to enter into the reporting system. Bias can be prevented to some extent by explicit definition of activities that then become standard for the organization.

Often standardization of activity descriptions manifests itself in the preparation of a dictionary of terms and activities. The dictionary serves to accurately identify completed activities and improves communication within the project group while providing the basis for a historical file of time and cost date. This file becomes useful for estimating future projects containing similar activities.

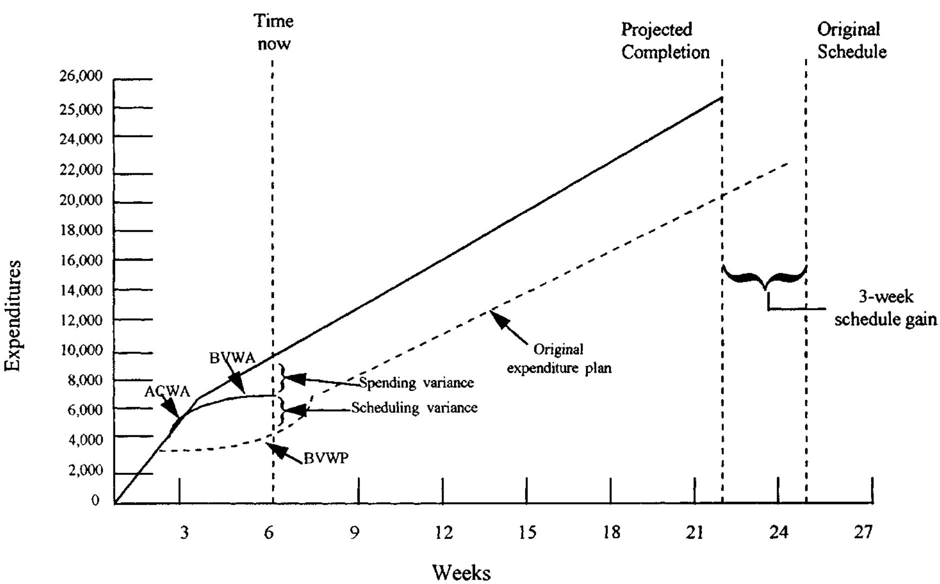


Fig. 67.30 Integrated progress chart for the structure of the TV transmission building A01-3-2. BVWA = budget value of work accomplished; ACWA, actual cost of work accomplished; BVWP = budget value of work planned. (Adapted by permission from G. Schillinglaw, *Managerial Cost Accounting,* 4th ed., Richard D. Irwin, Homewood, IL, p. 763.)

Finally, the frequency of reporting should vary from one project to the next, depending on the nature and complexity of the contract, the importance of the project to the organization, and customer reporting requirements.

67.5 A SURVEY OF COMPUTER SOFTWARE FOR THE MANAGEMENT CONTROL OF PROJECTS

There are currently more than 350 software packages available to assist in the management control of complex projects. These packages are designed to operate in mainframe, server, and personal computer environments. Many of these packages support group interactions and some even link project personnel working in different organizations. They range in price from $40 to $350,000.

Software packages are available for the purposes of constructing work breakdown structures; planning and scheduling; resource loading, leveling and constrained resource scheduling; financial planning and costing; performance analysis and reporting; multiple project planning, scheduling, and costing; and project graphing, including the drawing of project networks, schedules, and reports.

A complete list of these 350 packages is found in the 1995 Project Management Software Survey, published by PMI Communications, 323 West Main Street, Sylva, North Carolina, 28779. This survey describes the principal features of each software package, the hardware requirements, the price, and the address of vendors.

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