

PROJECT CONTROL FOR ENGINEERING

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CII was founded in 1983 to improve the cost effectiveness of the nation's largest industry. The members, who represent a broad cross-section of owners and contractors, believe that many of the problems that limit cost effectiveness are common ones, and that real improvements can be best accomplished in a cooperative environment with the benefits being shared by the construction industry at large.

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Project Control for Engineering

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INTRODUCTION

One of the most important challenges facing engineering and construction management today is the prevention of cost and schedule overruns of the type that have plagued major projects so often in the past. The multiple parties involved in a project (owner, engineer, construction manager, contractors, and subcontractors), the complexities inherent in a project, the pressure of time, increasing regulatory requirements, inflating costs of material and labor, and the uncertainties of nature combine to make major engineered construction a management nightmare. Obviously a project must have a formal project control system if there is to be success, and that system must encompass the engineering effort.

Project control is concerned with resource quantities, time, and costs. Planning and controlling of resources is generally accomplished within the cost control system. All resources, whether they be personnel, material, equipment, supplies, or services, are quantifiable and can be converted to a dollar amount. During the planning of a project, quantity and dollar budgets for these are established. During the controlling operation, actual quantity and dollar performance and rates of utilization are compared with planned performance.

Time and work progress are managed through the schedule. During the planning operation, engineering work tasks are scheduled to fit project requirements and a system for measuring progress of each task is established. During the controlling operation, status is reported against that system.

The benefits of an effective project control system are many. It documents the project plan and actual performance. It identifies problem areas and unfavorable trends. It is a communication tool. It allows project managers and other project participants to "keep a handle" on the work. It feeds into the historical database so that future planning of comparable work can be more accurate. Overall, the project control system is a major factor in the success of the project at hand and the planning of future projects.

Control of engineering activity is generally more difficult than control of construction activity because engineering tasks are more difficult to quantify and track between start and completion, tasks are more parallel and overlapping, and the responsibility for a given design often is shared among various disciplines. The challenge is particularly great on those projects in which engineering overlaps procurement and construction. Engineering work, however, can be controlled. Succeeding chapters of this publication provide details of a system for this control.

ORGANIZATIONS FOR ENGINEERING

General

A properly structured organization is key to effective management and control of any project. The planning and controlling of the engineering for a project, where multiple functional departments and many individuals are involved, is particularly complex. It is essential that the work included within the project be fully scoped and defined, and that responsibility be assigned for its accomplishment. Three types of organizational structures may be utilized for managing this work - a functional organization, a task force organization, or a matrix organization.

Functional Organization

A functional organization is the traditional pyramidal organization wherein each functional department (e.g., Engineering, Accounting, Construction) is organizationally independent of the others and handles all work within its area of expertise. Coordination between departments is handled on an informal basis and resolution of conflicts falls to the senior managers to whom the various departments ultimately report. This type of organization works well when a minimal amount of contact is needed between departments. Within a functional organization, project management becomes an additional duty of senior company managers. It is a feasible, though not particularly efficient, organizational arrangement for management of small projects; it is not effective for large projects.

Task Force Organization

A task force is an organization comprised of individuals assigned from the functional departments to the task force for the purpose of managing a project. Individuals assigned to the task force are committed full time to the project during the period of their assignment. A project manager is appointed and the other personnel are organized functionally under the project manager. The organization and personnel of the task force may change as the project moves through various phases. The major advantages of a task force are that it permits concentration of resources on a project and involves minimum management levels. This type of organization is particularly suited for large projects.

Matrix Organization

The matrix organization is a combination of a task force organization and a functional organization. In a matrix, there are two chains of command for each staff member, one along functional lines and the other along project lines. This is achieved by having the staff report to two managers simultaneously - a project manager for project direction and a functional manager for technical direction. The *project* team within the matrix is a group whose members are drawn from various functional departments of the organization and who are committed to support the project or task at hand. Project (team) managers are normally drawn from a pool of such managers. In some situations, both project managers and team members may simultaneously serve on more than one project team.

There are strong and weak matrix organizations. A strong matrix is one where the project team structure is preeminent - i.e., the project manager's authority over the individuals on the project team exceeds that of the functional managers. In a weak matrix, the reverse is true.

Matrix organizations are the most common and also the most complex form of organization utilized for management of engineering work. When well managed, they provide for maximum coordination, information exchange, and resource sharing. Matrix organizations are also the most economical form for management of multiple projects, none of which is large enough to warrant a full task force. The strong matrix is the preferred form².

The Status of Project Controls in the Organization

Project control, to be effective, must begin during the planning and budgeting of the work. It will continue during the conceptual and detailed engineering phases. If these phases are a part of a contract where engineering, procurement, and construction overlap, engineering project control will be integrated with procurement and construction project control.

The project control function is the "eyes and ears" of management at all levels and the source of project status information for the client. It is also an information center for every professional on the staff. Accordingly, it should be organizationally placed so that it responds directly to the project manager. It **must not** be treated as another accounting function, nor should its activity be decentralized among the functional groups. And it must be recognized as an integral part of management, not as a police force! Management must assess the information provided, then take the necessary steps to implement the action needed.

PROJECT CONTROL BASICS FOR ENGINEERING

Types of Engineering Contracts

In industrial construction it is common for engineering, procurement, and construction to be handled in parallel and with some overlap - these are called *Engineering-Procurement-Construction (E-P-C) projects* for purposes of this publication. The engineering portion of the project may be part of a turnkey arrangement administered within a single agency or it may be handled as a separate contract that must tie-in with the contracts of others.

It is possible, however, for engineering to precede completely both procurement and construction. An engineering contract in this case is referred to in this publication as *Engineering-Only (E-O)*. The E-P-C format is the more challenging of the two from a project controls viewpoint.

The Nature of Engineering Work

The primary products of engineering work are documents to guide both the construction of a facility and the manufacture of engineered equipment for installation in such a facility. Other products are studies, procedure and operating manuals, and various consulting services.

In performing its work, the engineering group is generally organized around engineering disciplines (civil, architectural, structural, mechanical, electrical, *etc.*) or specialty services (model shop, procurement, environmental studies, economic studies, *etc.*). These production units of the organization have products such as drawings, specifications, models, manuals, studies, and procurements. Supporting them are such functions as word processing, computer services, accounting, personnel, and others.

Some owners maintain internal organizations for accomplishment of conceptual and/or detail engineering of their facilities. But much if not most of it is handled under contract with an engineering firm. Many contracts in the latter case are reimbursable, although fixed-price contracts are becoming more common, and there are reimbursable contracts with ceilings, targets, or incentives. The typical reimbursable contract is handled in this fashion:

- Professionals within the production units are identified as reimbursable. The client agrees to pay for each hour of work of those reimbursable individuals in an amount equal to the base hourly pay of each individual times a multiplier. This multiplier is in the range of 1.5-2.5.

- Other items are identified as “reimbursable directs.” These are items such as travel, reproduction, computer services, and communications. In most cases, their costs are passed through to the client without markup.
- Items such as general management, accounting, personnel services, and secretarial services are “non-reimbursable directs and indirects,” and are not charged directly to the client. These costs are accounted for within the multiplier noted above. That multiplier also accounts for profit (unless the project is cost-plus) and for personnel fringe benefit costs (burden) such as vacation, medical, FICA, and retirement.

If the contract form is fixed-price or other than the reimbursable described above, the engineering agency still must account fully for the direct costs, project level indirects, general overhead, and any contingency and profit in the pricing.

Planning and Budgeting

As noted previously, there are activities of direct work in an engineering contract and each has a cost. Other activities that are support in nature, both direct and indirect, are only cost items. Contract progress is tracked against the work activities; costs are tracked against all activities and other cost items. Thus, the project control system must be designed to control both work and cost.

When planning any project, it is desirable to divide the project into well-defined, manageable parts for purposes of control. By controlling the individual parts, it is possible to establish control of the total project. Figure 1 is a matrix representation of the budget that might be established for a typical engineering project. Certain items on this budget include allocations of work-hours as well as costs. Others are budgeted only for cost. Experienced engineering organizations are able to estimate quite accurately the number of engineering documents and the work-hours required. They are also able to estimate the quantity and work-hour requirements for their other products and the costs of other reimbursables and non-reimbursables and, having done this, to establish a multiplier. These estimates become the basis for project control.

Control of work is best based on control of budgeted work-hours for individual work activities (see discussion in following paragraphs for examples). As part of this control, there must be some method for evaluating percent complete of each activity. The methods are established during the planning operation. Methods available are summarized in Appendix A.

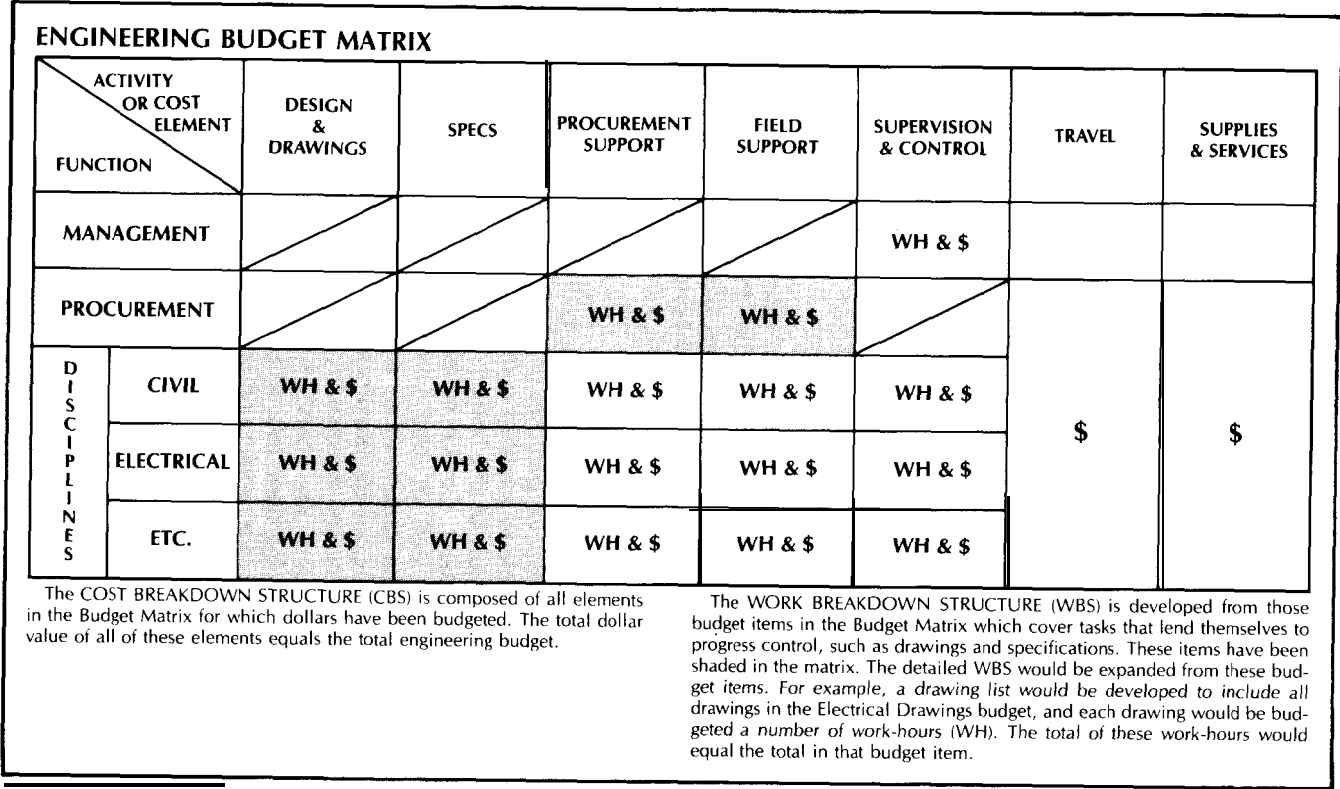


Figure 1. Engineering Cost Breakdown Structure and Work Breakdown Structure

Terminology

Remaining discussion will describe a variety of terms used in the controlling process. Figure 2 may prove helpful in explaining and interrelating these terms. The example uses a simple process system composed of two vessels and interconnecting piping. It traces the flow of engineering work and relates that to the components of the completed process system.

Breakdown Structures and Work Packages

The Cost Breakdown Structure (CBS) for the project includes every element of cost for the project. In effect, it is a summary of the budget by category. The total of all categories equals the total project budget. Referring again to Figure 1, this matrix is a visual representation of the CBS for an example project.

The Work Breakdown Structure (WBS) for the project relates only to the engineering work products that the project manager chooses to status as a basis for progress reporting. Drawings are traditionally a status item. Designing, specification writing, study preparation, model construction, and equipment/material procurement involve deliverables, and thus are other logical choices. The more of these tasks chosen for control, the more positive and informative the control system will be.

On Figure 1, the shaded portions are the budgets for those elements of the CBS which will comprise the WBS for this example project. In this example, only Design & Drawings, Specs, Procurement Support, and Field Support transactions have been chosen for work control. The activities accounted for within these budgets are essentially the greatest level of detail in the WBS. Thus, the WBS is incorporated within the CBS. Actually, the complete WBS for the project will have the total facility to be designed as the ultimate summary level. The facility is then divided into well-defined areas, systems, and structures which in turn can be further sub-divided into well-defined sub-areas, sub-systems, and sub-structures to form a hierarchical WBS describing the total facility to be constructed. The WBS is continued beyond that point to identify those activities required to prepare documents that are used to guide both the construction of a facility and the manufacture of engineered equipment for installation in such a facility. A work package is any one set of these activities which are targeted on a given procurement or construction need date.

A contractor may include selected indirect activities such as supervision or project controls in a progress control system, and use the *Ratio or Judgment* method of reporting status (see Appendix A). In such a case, the CBS/WBS relationship will be more like that shown in Figure 3. However, indirect functions do not directly contribute to deliverables and inclusion of them will distort progress on deliverables.

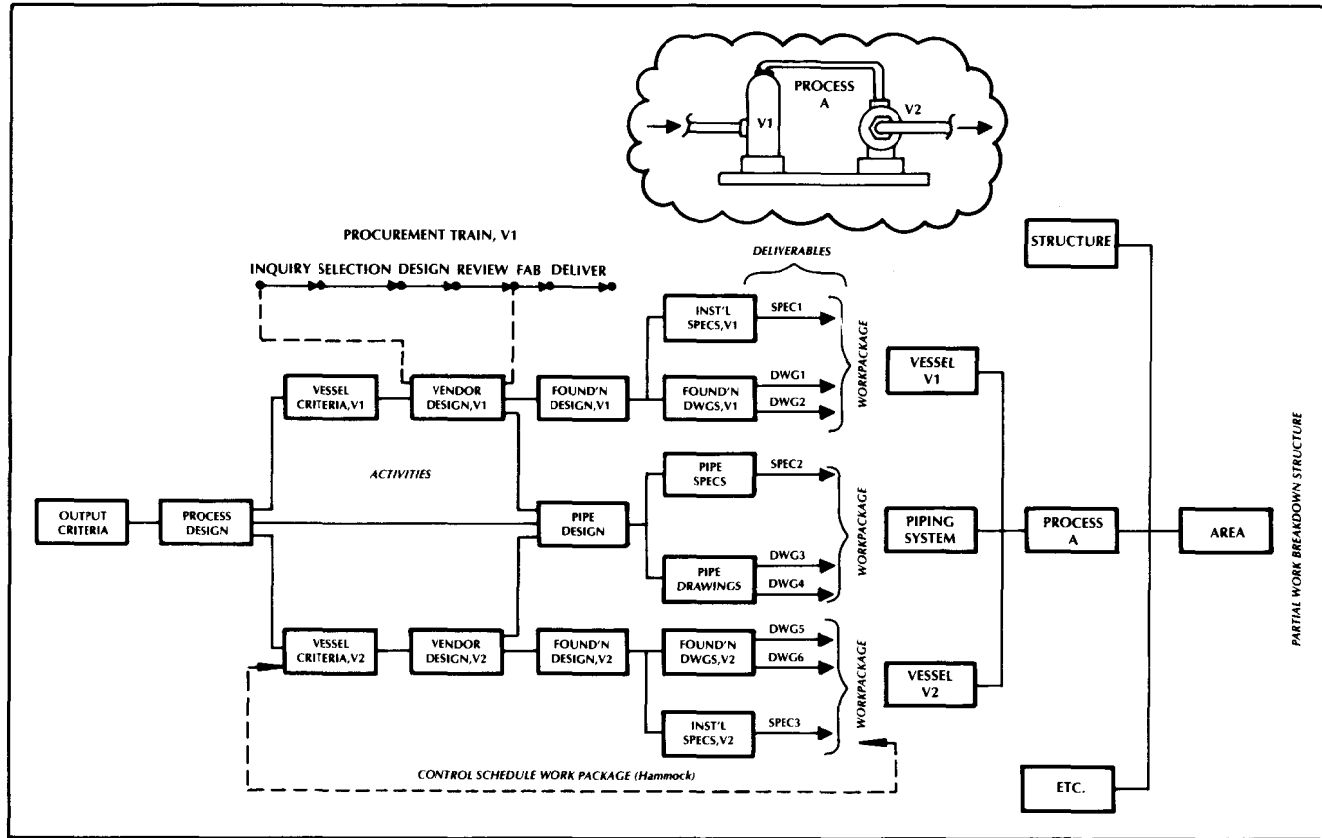


Figure 2. Example to Illustrate Logic and Use of Terms

What is the practice in industry on this subject? Reference 2 is a report from a research project which provided much of the background material for this publication. One area investigated was progress control; firms were asked which work items were included in their progress control system. To catalog responses, the breakdown of the total effort in an engineering project was estimated to average 40 percent to drawing development, 15 percent to specifications development, 10 percent to design support activities, 25 percent to procurement activities, and 10 percent for other activities. With these assumptions it was found that four of six firms use only 55 percent of the total work for formal progress tracking, while one tracks 80 percent and another 90 percent.

Schedules

Different levels and types of schedules are appropriate for control of engineering work. The most detailed schedule control occurs in the controlling of individual engineering deliverables. At that level, bar chart schedules may be appropriate, but for effective schedule control the roll-up of such tasks must be related to activities in a CPM-formatted engineering schedule.

<i>Activities</i>	Indirects ³	Labor	Equip.
Supervision	\$	WH \$	\$
internal Support	\$	WH \$	\$
Procurement	\$	WH \$	\$
Study	\$	WH \$	\$
Design	\$	WH \$	\$
Document Preparation	\$	WH \$	\$
Document Review	\$	WH \$	\$
External Support	\$	WH \$	\$
Other ⁴	\$		

Notes: 1. The CBS is composed of all activities in the matrix for which dollars (\$) are budgeted. The total value of these equal the project budget.

2. The WBS is composed of those direct labor activities in the matrix for which work-hours (WH) are budgeted. They may be used for work progress measurement.

3. "Indirects" includes supervision above first level, staff, facilities, supplies & services, travel, etc.

4. "Other" includes office overhead, contingency reserve, profit, etc.

Figure 3. Example CBS/WBS Relationship ^{1,2}

The project's control schedule may be in barchart form with milestones and key interfaces on an E-O contract, but networking is certainly appropriate. On E-P-C projects, the control schedule should be in network format and interrelate with the procurement and construction schedules - engineering work package completion usually constrains the start or continuation of a procurement or construction activity on E-P-C projects. Thus, need dates for dependent work packages become milestone dates on the engineering portion of the control schedule. On E-P-C projects it is **absolutely essential** that a logic trail be established among all activities contributing to project completion. The trail is best established if network relationships are created among all activities. This philosophy must be balanced against having too much detail on the control schedule since it must be simple enough to permit human review and analysis. The solution is to keep the project's control schedule at a network summary level and to treat its engineering, procurement, and construction activities as hammocks supported by individual detailed schedules. When this is accomplished and the total system is integrated, it will be possible to trace the effects of any changes and deviations throughout the project. As noted previously, engineering work packages are the activities on the control schedule and as such are the hammocks for more detailed subnets that trace both sequential and parallel steps in accomplishing the activities included within the work package. More on this subject is contained in the CII publication, *Model Planning and Controlling System for Engineering-Procurement-Construction of Industrial Projects*.

Schedule control and updating will take several forms. Approved changes will be the basis for changing the control schedule. Recognizing that actual performance will seldom mirror the control schedule, controllers also will maintain a working schedule which documents performance to date and plans work from that point. Short-term, detailed scheduling will be used for planning work for the near term future (30-90 days). Throughout the project, the control schedule will serve as the target, and as such, must be the basis for all reporting of items such as schedule conditions, progress, and others.

Codes of Accounts

A relatively complicated system of coding is needed for control of engineering work. First, a two-part code will reflect the CBS matrix illustrated in Figure 1, one part representing the function, the other the activity. Engineering personnel will use this code when logging their time so that it is charged to the proper budget category.

Another numbering system(s) is appropriate for drawings, specifications, and other deliverables. These numbers can be sequential in nature and **need not** include any cross-reference to the WBS. Drawing, specification, and other deliverable lists and control numbers are developed during the planning and budgeting phase. The deliverables coding is needed for cross-referencing to work packages. It is also useful for personnel working on these items to use in charging time on their time cards. In this case it is used in conjunction with the CBS identifier as a first step in work-hour tracking. For example and referring to Figure 1, assume that the electrical discipline function has the code "EL," that the budget category is "design and drawings" (code "01"), and the drawing number is 4567 - the coding for work on this would be:

EL-01-4567

For activities that contribute to more than one deliverable (e.g., various criteria development), the deliverable portion of the code can be replaced by an activity code. This numbering system is particularly useful in cost control since it collects data at the budgeting (CBS) level. This format also permits summary of data against function, activity, or specific deliverable or activity type for historical purposes. It can also be incorporated in the schedule activity identification numbers used at the detailed (sub-ham-mock) level.

Still another coding system is needed for work packages. Since work packages are really an extension of the WBS, the codes for work packages are really a detailed extension of the WBS code. A typical engineering work package includes an assortment of engineering documents and any given document can be a component of several work packages, and thus this numbering system should be separate from that used for included components. This code structure is used on the engineering portion of the control schedule. Included documents will be cross-referenced to work packages and work packages to the WBS within datasets of the integrated control system.

The project's WBS will have a hierarchical code structure that permits summary of information to any level of that structure. It will be used in conjunction with work package identifiers in scheduling.

The materials tracking system will require a coding system to identify equipment items and commodities so that their tracking can be integrated with the schedule. This coding system will also permit generation of equipment, instrumentation, and other lists used within the control system.

Progress Measurement

Percent complete is determined by the method chosen during the planning operation for the task in question (See Appendix A). Earned value techniques are used for summarizing overall work status. The earned value of any one item being controlled is:

$$\text{Earned Work-Hours} = (\text{Budgeted Work-Hours}) \times (\text{Percent Complete})$$

Note: Budgeted Work-Hours equal original budget plus approved changes.

Overall percent complete of the project or of a work package is found by this formula:

$$\text{Percent Complete} = \frac{\text{Sum of Earned Work-Hours of Tasks Included}}{\text{Sum of Budgeted Work-Hours of Tasks Included}}$$

Trends can be tracked through various indices. The Productivity Index (PI) and the Schedule Performance Index (SPI) are particularly useful for this purpose. The PI provides a comparison of the number of work-hours being spent on work tasks to the hours budgeted and is an indicator of productivity. The formula is as follows:

$$\text{PI} = \frac{\text{Sum of Earned Work-Hours of Tasks Included}}{\text{Sum of Actual Work-Hours of Tasks Included}}$$

Note: For the above to be a true indicator of productivity, only those tasks for which budgets have been established should be included in summations.

The SPI relates the amount of work performed to the amount scheduled to a point in time. The formula is:

$$\text{SPI} = \frac{\text{Sum of Earned Work-Hours to Date}}{\text{Sum of Scheduled Work-Hours to Date}}$$

Note: Scheduled work-hours used in this formula are summarized from the task schedules.

In both the PI and SPI formulas, an index of 1.0 or greater is favorable. Trends can be noted by plotting both "this period" and "cumulative" PI and SPI values on a graph.

While the SPI for the total project or for a work package is somewhat of an indicator of schedule performance, it tells only part of the story. The SPI only compares volume of work performed to volume of work scheduled. There can be an SPI in excess of 1.0, but the project can still be in danger of not meeting milestones and final completion dates if managers are ex-

pending effort on non-critical activity at the expense of critical activity. The SPI does not show if work is being completed in the proper sequence. Thus, as part of schedule control, controllers must regularly examine the schedules of all included tasks in each work package so that any items behind schedule can be identified and corrective action taken to bring them back on schedule.

Cost performance on the project is tracked by comparing actual costs to those in the budgets of the CBS. Unfortunately, significant lags between incurrence of cost obligations and receipt of invoices or other cost notification for many accounts can make it difficult to maintain a timely, responsive cost control system. It is possible to use an earned value approach for cost control if an owner or contractor so desires. Appendix B describes such a system as utilized on some U.S. Government contracts.

Procurement Activity

Two types of procurement activity are associated with engineering. The first type is the procurement of equipment/material to be engineered by others. With this type procurement, the design engineers develop performance specifications and other criteria for an item and provide them to the selected vendor. The vendor designs the item to meet the specified criteria and forwards the design documents to the engineer for review. Following drawing approval, the vendor will fabricate and deliver the item. Some engineering activity may have to be put on hold until approved vendor documents are available (e.g., foundations and piping connections). Often the timing for these vendor documents to support follow-on engineering is more of a determinant for the schedule of early procurement train activities than the item's need date for construction.

A second type of procurement is the more general type which results in the delivery of off-the-shelf pieces of equipment or commodities.

An engineering firm may have either or both types of the procurement actions included in its contract on an E-O contract. On an E-P-C contract, it would be normal for the firm to have both. Regardless of what agency has procurement responsibilities, it is essential that procurement be included in the controlling system for the project. It is also essential that procurement activities constraining engineering design (and vice versa) be related to the activities which are constrained.

A given procurement action is a train of sequential activities. Each of these activities must be included in the detailed schedule, although the overall procurement of a component can be a single activity on the control schedule. For procurement tracking, each procurement train can be treated as a unit and tracked using the *Incremental Milestone* method. Or, each train activity can be tracked separately using a method most appropriate to that activity (Appendix A).

Controlling

The system described is intended to provide the project manager and other project participants with the information needed for control of the project. Data generated from the system are continually analyzed for the purpose of identifying trouble spots or unfavorable trends. If the system has been designed properly, timely reports will be available so that corrective action can be taken when and where needed.

Historical Data

Planning of future projects relies heavily on experience on past projects. Datasets within the system should be designed to summarize and accumulate experience data in a format directly usable in future planning.

System Design and Computer Selection

Integrated project control is an objective in the selection or design of the computerized project control support system. The following features are desirable in the system.

- The computer software should have both a scheduling module and database management capability.
- The schedule module must handle network type scheduling.
- The databases should be linkable to the schedule module.
- A graphics capability should be included which is capable of producing network logic diagrams, barcharts, histograms, and graphs from system databases.
- The system should be capable of generating user-designed reports using data directly from any combination of the datasets, and also should be capable of performing calculations or summations from the data.
- Databases should be structured so that it is not necessary to enter a piece of data more than once.
- The system should provide the project controls capabilities described elsewhere in this publication.

Improved capabilities now allow microcomputers to be used for stand-alone project control on many projects. In choosing hardware and software for a microsystem, users must insure that candidate systems can handle both the scheduling and database management requirements. Control of engineering is a complicated procedure, and therefore a database management capability of considerable capacity is required.

DOE/DOD Cost & Schedule Control Systems Criteria

The U.S. Departments of Energy (DOE) and Defense (DOD) have adopted a policy concerning control systems used by contractors on certain types of projects. This policy is described under the Cost & Schedule Control Systems Criteria (CSCSC) for Performance Measurement. A brief description of CSCSC features as applied to engineering and as related to previous sections of this document is in order. Appendix B is an overview of the system and Reference 3 is a publication which describes the system in detail.

OTHER OBSERVATIONS AND FINDINGS

Recent research⁷ has provided a variety of other observations and findings relating to project control of engineering. Several of significance are summarized in the following paragraphs.

Obtaining Project Participant Support

In order for a project control system to be effective, it must be understood and accepted by all who use it. Unfortunately, it is a fact that very few engineering programs in the universities and colleges of the United States include any required course material on planning and controlling engineering work, nor are such subjects as procurement, construction methods, and constructability included. Thus, in-house training of engineering personnel in these subjects is a must if management is to expect their understanding, commitment, and support. Additionally, individuals providing data to the system should be given a voice in the design of input format and the system should be designed to provide feedback to the participants.

The Key Role of the Project Manager

Management commitment to a program is essential if a program is to succeed. Thus, in the case of project controls, it is essential that project managers understand the theory and potential of a modern project controls system. Once a project manager is committed, steps can be taken to assure understanding and commitment of all other project participants.

How Much Should Be Spent on Project Controls?

The portion of the budget which contractors spend on project controls varies. Since every project is unique and client requirements differ, it is difficult to determine the exact level of control needed in terms of project budget. However, based on projects observed, it appears that good project controls performance is best assured if at least 8 percent of the engineering budget is committed to this effort.

Changes

Project control systems are based upon planned budgets and schedules. When changes are introduced, the plans and schedules must be revised. Some changes are the result of scope change; others result from value engineering, constructability studies, or engineering error. Unfortunately, changes seldom affect only one engineer or discipline; they can have a ripple effect on the entire project. Thus, it is essential that an engineering organization have formal scope control and change control programs. More on this subject is contained in the CII publication, *Scope Definition and Control*.⁴

What Makes Projects A Success?

Those interviewed were asked to identify the factors that distinguish successful and unsuccessful projects, with the following results:

Successful Projects:

- Well-defined scope
- Early, extensive planning
- Good leadership, management, and supervision
- Involved, positive client relationship
- Proper chemistry among project participants
- Quick response to changes
- Engineering managers concerned with total project, not just engineering

Unsuccessful Projects:

- Ill-defined scope
- Poor management
- Poor planning
- Poor communication between engineering and construction
- Unrealistic schedules and budgets
- Poor personnel quality
- Excessive changes
- Poor project controls

The Future

Advancing technologies and new ideas can be expected to influence project controls in the future. The following have been identified:

Computer-Aided Design (CAD). Computer-aided design has become commonplace in engineering organizations, but systems which directly tie into estimating and project controls are in their early stages. In the future there should be systems which automatically generate equipment and material lists that feed into the estimating system and resource-load the schedule while also prompting procurement activity.

Expert Systems. Expert systems would be valuable during conceptual engineering to generate major equipment lists, bulk quantities, and other information for various processes and to produce resulting cost estimates. Such systems would also greatly simplify value engineering studies during the conceptual engineering phase of a project and facilitate various decision processes throughout the detail engineering phase. Other applications include forecasting, risk analysis, and personnel training.

Engineering Control Based on Quantities Designed. Traditional tracking of engineering work is based on engineering units of production. Some firms are experimenting with a tracking system based on quantities designed (e.g., cubic yards of concrete, linear feet of pipe). Such a system would parallel engineering control with construction control. This approach could be automated within CAD: However, development of good quantity estimates during the budgeting process is a major hurdle for this approach.

Inclusion of Quality in Project Control. Time, cost, and **quality** control are the goals of every project manager, yet quality control is not formally included in the project control system. Use of a quality performance index along with other indices used in control systems should be considered for the future.

SUMMARY AND CONCLUSIONS

Effective project control of the engineering effort can be attained. Modern techniques with supporting computer systems are available, but the industry has been slow in accepting them.

It takes organization and qualified people to manage and control complex engineering work. Various organizational forms are possible, but a task force organization is the most efficient for the larger projects; a strong matrix management approach is more practical for smaller projects.

The project control system must be designed to control both work and cost. The system must encompass planning, scheduling, monitoring, reporting and analysis, forecasting, and historical data collection. Subsystems within the total system must be available to track procurement activity and to generate and maintain equipment lists, instrument lists, and other summaries associated with design engineering work. The design of the system should be based on the principle of integrated project control, and be flexible enough to handle large and small projects while also responding to special client needs.

The entire professional staff of the engineering organization must be committed to and support project control and be trained in the operation of the company's system. If properly designed and supported, such a system should provide the control needs of management and essential feedback to individual professional personnel.

Establishment of an effective project control system will require money and the establishment of a formal project controls organization. Approximately 8 percent or more of the costs budgeted for an engineering project should be allocated for project control to be effective. Eight percent may seem high, but the potential cost and time savings attributable to an effective project control system far outweigh the cost of establishing and maintaining that system.

APPENDIX A

PROGRESS MEASUREMENT SYSTEMS

Basic Methods

The determination of percentage completion on a single activity can usually be handled under one of the following four systems:

Units Completed. This method is suitable when the total scope of an activity consists of a number of equal or nearly equal parts, and the status is logically determined by counting parts completed and comparing that to the total number of parts included in the activity. Ideally, each unit is of relatively short duration. While this method has considerable application in the construction phase, it has limited use during engineering. A possible application is in the writing of a number of specifications of a given type where all specifications are considered to have essentially equal weight.

Incremental Milestone. This method is appropriate for activities of significant duration which are composed of easily recognized, sequential sub-activities. Percentage completion values are established based on the effort estimated to be required at each milestone point relative to the total for the activity. This method is ideal for control of drawings and can be used in procurement. A typical example for drawing control is:

Start drafting	0%
Drawn, not checked	20%
Complete for office check	35%
To owner for approval	70%
First issue	95%
Final issue*	100%

**Only when no additional engineering is anticipated*

A typical example for procurement is:

Bidders list developed	5%
Inquiry documents complete	10%
Bids analyzed	20%
Contract awarded	25%
Vendor drawings submitted	45%
Vendor drawings approved	50%
Equipment shipped	90%
Equipment received	100%

Start/Finish Percentages. This method is applicable to those activities which lack readily definable intermediate milestones, and/or the effort/time required is difficult to estimate. For these tasks, controllers credit 20-50 percent when the activity is started and 100 percent when finished. The reason that a percentage is assigned for starting is that this compensates for the long period between start and finish when no credit is being given. This method is appropriate for work such as planning, designing, manual writing, model building, and studies. It can also be used for specification writing.

Ratio or Judgement. This method is applicable to tasks such as project management, constructability studies, project controls, and comparable activity which involves a long period of time, has no particular end product, and is estimated and budgeted on a bulk allocation basis rather than on some measure of production. It can also be used on those tasks for which the Start/Finish method is appropriate. Percent complete at any point in time is found by dividing hours (or dollars) spent to date by the current estimate of hours (or dollars) at completion.

Summary Levels

Determination of percent complete of summary level accounts is found by use of earned value as discussed in Chapter 3.

APPENDIX B

THE DOE/DOD COST & SCHEDULE CONTROL SYSTEMS CRITERIA

The CSCSC System

Following are key features of the DOE/DOD Cost & Schedule Control System Criteria (CSCSC) for Performance Measurement.

Breakdown Structures. A Work Breakdown Structure (WBS) for the project is developed similar to that previously described in this document. This breakdown is product-oriented and defines the columns of a matrix. The rows of the matrix are defined by an Organization Breakdown Structure (OBS), which details in hierarchical fashion all organizations responsible for the work. The rows and columns meet to describe cost accounts which include all specific tasks to be performed by an organization with respect to an item on the WBS. A typical cost account might be the electrical design by Firm A of a specific system. It can also be an indirect item such as quality control or supervision. Cost accounts can be further broken down into specific tasks such as drawings and specifications. The term *work package* is used to describe both tasks and combinations of tasks in the CSCSC system. The CBS of Figure 1 is essentially a simplified version of the CSCSC's WBS/OBS matrix.

Terms. A number of terms are established for use in reporting the status of a project. These are:

Budgeted Cost for Work Scheduled (BCWS). BCWS is the cost account or total contract budget less any "management reserve" (funds held in reserve to be used in case of scope growth). It is time-phased based on the cost-loaded schedule.

Budgeted Cost for Work Performed (BCWP). BCWP is the earned value, expressed in dollars, for all work accomplished during a period. It is equal to the sum of the budgeted costs of that work.

Actual Cost of Work Performed (ACWP). ACWP is the total of all costs actually incurred in accomplishing work within a given period and recorded at the cost account level.

Budget at Completion (BAC). At the cost account level, BAC is the total authorized budget for that account. For the project, it is the total including management reserve.

Estimate at Completion (EAC). EAC is the latest cost estimate for a cost account or the total project.

Cost Variance (CV). CV is the difference between BCWP and ACWP, and shows whether work performed has been costing more or less than budgeted.

Schedule Variance (SV). SV is the difference between BCWP and BCWS, and shows whether more or less work was performed than scheduled.

At Completion Variance (ACV). ACV is the difference between EAC and BAC, and shows whether an overrun or underrun is expected.

Cost Performance Index (CPI). CPI is an index found by dividing BCWP by ACWP. It can be calculated on a "this period" or cumulative basis, and when plotted on a graph is an effective way of showing cost trends. A CPI of 1.0 or greater is favorable. It is an alternate presentation of the CV.

Schedule Performance Index (SPI). SPI is an index found by dividing BCWP by BCWS. It compares the volume of work being performed to the volume scheduled. As with the CPI, it is suited for trend charts. An index of 1.0 or greater is favorable. It is an alternate presentation of the SV.

Cost Accounts. These take one of three forms:

Work Packages. Work involving easily identified end products.

Level of Effort (LOE). Support type activity which does not have a final product and which is not specifically related to individual work packages. Management, project controls, and other staff activities are typical LOE cost accounts.

Apportioned Effort. Support activities which are directly tied to individual work packages. Quality inspection and testing is an example of a cost account in this category.

Applicability of CSCSC to Civilian Design Projects

The structure of CSCSC is complicated and difficult to use. It was designed for high-dollar value, cost-reimbursable, and complex defense and energy projects, not the more typical commercial and industrial projects. It monitors both cost and work through a cost control system. Unfortunately, costs do not flow into a project in a timely manner, thus a work control system based on cost is not timely. Most contractors prefer a work statusing system based on work-hours and work quantities (normally reported daily) for day-to-day management of work. If operating under CSCSC, contractors will usually employ a work-hour/work quantity system for internal control in addition to complying with CSCSC for reporting to DOE or DOD. The CSCSC recognizes and allows such supplementary control systems by contractors.

The full Organization Breakdown Structure (OBS) is another feature of CSCSC that has marginal value in the management of civilian projects. While the government finds such a structure useful in the management of huge, multi-contractor, cost-reimbursable research and development projects, contractors on civilian work generally will find that their CBS incorporates whatever organizational identification is needed.

NOTES

NOTES

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