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PROJECT CONTROL FOR CONSTRUCTION

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* CII Application Notes:                                               *
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* 1. Character(s) preceded & followed by these symbols (. -) or (+ ,)  *
*    are super- or subscripted, respectively.                          *
*    EXAMPLES:  42m.3-  =  42 cubic meters                             *
*               CO+2,   =  carbon dioxide                              *
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* 2. All degree symbols have been replaced with the word deg.          *
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* 3. All plus or minus symbols have been replaced with the symbol +/-. *
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* 4. All table note letters and numbers have been enclosed in square   *
*    brackets in both the table and below the table.                   *
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* 5. Whenever possible, mathematical symbols have been replaced with   *
*    their proper name and enclosed in square brackets.                *
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Project Control
for
Construction

Prepared by
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Cost/Schedule Controls Task Force

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1. INTRODUCTION

Management of the construction portion of a project is one of the most challenging management assignments in the industrial world. Upon contract award and in a short period of time, the field manager must finalize the preliminary plans developed during the pre-bid or proposal phase, order materials and construction equipment, erect construction support facilities, and recruit and mobilize a construction force. Then, while fighting the vagaries of weather, material deliveries, regulations, local politics, changes, and other intervening factors, the manager must guide the efforts of an unpredictable labor force towards a completion date. Of course, the objective is to complete the project under budget and on schedule while surpassing the quality requirements of the specifications.

Meeting such a challenge would be impossible without a plan and a control system; construction does not just happen. The Construction Industry Institute (CII) publication, Contractor Planning for Fixed-Price Construction provides a model planning process for a fixed-price construction project. The CII publication, Model Planning and Controlling System for Engineering, Procurement, and Construction of Industrial Projects, describes the process for the EPC project. The resultant plans from this process, collectively referred to as the Project Execution Plan, provide the basis for control. It is then a matter of structuring control activities so that actual performance can be compared to planned performance in a format which provides a valid, timely picture of project status while also isolating problem areas requiring particular management attention.

This publication deals with the cost and schedule control of a construction project. It is based in large part on the research report identified as Reference 1, although the CII Cost/Schedule Task Force has included additional material. The report deals primarily with these controls as applied to fixed-price projects with engineering essentially complete, since their control is considered to be the most challenging. However, variations for other types of contracts are provided.

Chapters 2 through 5 of this publication provide basic guidance and techniques for establishing baselines for control, measuring work progress, and reporting and analyzing. Chapter 6 then addresses the in-process management of the project when the realities of the workplace dictate detailed short-range planning and the management of variances.

Numerous acronyms are utilized in this publication. Although each is defined when first used, a summary listing with equivalent full titles is provided in the Appendix.

2. GENERAL

Project Formats

Construction can be accomplished under several basic contracting formats. These formats create different contractual relationships and reporting responsibilities, and thus affect the project controls function.

Single General or Prime Contractor (GC). Under this form, the contract for construction is between the owner and one contractor who has full responsibility for accomplishing the construction. The GC normally has the option to use any combination of direct-hire and subcontracting desired, although the owner may establish Minority Business Enterprise or Women Business Enterprise (MBE/WBE) goals or reserve the right to approve all subcontractors and major vendors. The contract can be either fixed-price (lump sum, unit price, or combination thereof) or reimbursable. Special features such as a guaranteed maximum cost and incentive features such as target cost or work-hours with shared savings/penalties, milestone bonus/penalties, or other performance bonuses also may be included. The GC will be responsible for establishing and operating the project controls system. Under both forms, the owner can be expected to require submission of a schedule for the project and there must be some agreed-upon mechanism established for progress payments. If fixed-price, the information provided the owner is normally limited to that needed to verify physical completion and schedule status.

Multiple Primes. This format is quite common on large projects that are managed by a construction manager (CM), with the CM function being handled by the owner or some agency under contract to the owner. The project is divided into major components such as site preparation, foundations, structural steel, and major piping, and separate contracts are awarded for each component. The contracts may be between the owner and the contractors or between the CM and the contractors. The administration of these contracts is essentially the same as for the GC format except that the individual contractors report directly to the CM. Normally, the CM will establish the overall project controls system and require the individual contractors either to operate within that system, which is operated as a network, or to provide information to the CM's project control staff in specified formats.

Turnkey. This format refers to a project wherein total management of engineering, procurement, and construction is given to one firm by the owner. That firm may choose to handle all functions using its own resources or may subcontract portions of the total to the others. Some turnkey projects are totally reimbursable. Others have certain portions reimbursable, usually engineering and procurement, with construction negotiated on a fixed-price basis after engineering definition is complete enough to permit this. The turnkey contractor will establish and maintain a project controls operation that integrates all activities.

Owner as General Contractor. Occasionally an owner will maintain a project management staff that directly manages company projects by using some combination of direct-hire and subcontracting. Included will be an owner-operated project controls system.

The CII publication, Impact of Various Construction Contract Types and Clauses on Project Performance, provides additional information on contracting formats.

Contracting Party Viewpoints and Interests

Each of the contracting parties - owner, engineer, CM, prime contractors, and subcontractors - are interested in project controls. In establishing any project controls system, the following interests must be accounted for:

Owner. The owner seeks assurance that the project will be delivered on schedule, within budget, and be of the desired quality. The owner also has the right to know what is being paid for with each request for payment. Thus, the project control system must be designed to provide the owner with the planned schedule and regular updates of actual schedule performance. If the contract is fixed-price, an agreed-upon mechanism must be established for measurement of work in place so that invoices for periodic payments are non-controversial. Under the fixed-price mode, the owner should not request detailed contractor cost information except as required to validate periodic payments. If the contract is reimbursable, the contractor must share all schedule, cost, and work-hour information with the owner. In fact, the owner may provide part of the staff for the project controls operation. On all contracts, the owner should receive summary cost and schedule information on the project for historical purposes. This can include workhour expenditures.

On most contracts the owner will establish scheduling guidance. The simplest guidance is the required date for completion and required contractor mobilization date. More likely, additional guidance in the form of a summary schedule or listing of milestone dates will be provided to correspond with expected delivery dates of owner-furnished items, coordination points with other contractors or operations, or key dates in start-up sequences. In some cases the owner will dictate a detailed schedule and perhaps the code of accounts.

For tax, regulatory, or other legal purposes, the owner may require accumulation of project cost data in a specific format. An example is that required by the Federal Energy Regulatory Commission (FERC) on energy projects. Such reporting requirements must be described in detail in the contract documents so that the contractor can set up the project controls system to accommodate them and, in the case of a fixed-price contract, properly account for this additional effort in the contract pricing.

The owner may maintain a staff on site to protect owner interests and to expedite any owner review or approval responsibilities.

Engineer. The involvement and interest of the engineer in project controls will be related to the level of completion of the design at the time construction commences. If engineering and construction are overlapping, the engineering activities must be closely linked with construction and procurement and become part of the Control Schedule. Obviously, if design drawings and specifications are complete for the contract, engineering work will not be part of the schedule. For further information see the CII publication, Project Control for Engineering.

CM. The CM is an agent of the owner, thus his interests will be the same as that of the owner for each of the contract forms.

General or Prime Contractor. Every contractor is interested in detailed control of the contract, whatever the contract form. On a fixed-price contract, such control best assures realization of profit and achievement of the benefits of any included incentive provisions of the contract. On all contracts, the contractor wants to accumulate as much information as possible for inclusion in the historical database so that subsequent projects can have the benefit of more complete planning data. Finally, a contractor wants to perform well since this is the best way to impress owners and assure continued work.

Subcontractors. Their interests are the same as those of the prime contractor.

Project Control Organization and Operations

Project controls is a major function on a construction project that is equal with engineering, business management, procurement, and quality control. As the eyes and ears of management, it should be placed organizationally to respond directly to the field project manager. By no means should it be an element under accounting or data processing. Placing it under project engineering, while not illogical, is not recommended because that operation already has enough responsibilities to fully absorb the attention of the project engineer. This approach also opens the possibility of restricting or prohibiting the flow of control information to other interested parties. The project controls staff functions most effectively when in an independent mode.

A computer system will be required to support project controls on all but the smallest of projects. This system should be operationally independent of other systems, such as accounting and payroll, since the system needs to be available at all times. It cannot afford to wait out the production of the payroll. Fortunately, with the capabilities of modern micro and minicomputer systems and associated project controls software, the independence of project controls is affordable and easy to achieve. While the project controls system should be operationally independent of the accounting system, it is desirable to link the two since much of the raw input data is used in both systems. This linking should be designed so that data input is needed only once.

Project controls personnel should be individuals familiar with field operations. Project controls work provides experience in cost, schedule, and materials management, and is a logical step on the career ladder for project management.

The project controls function is a key element of proactive project management. As such, its staff should be represented in all work planning. It is the guardian of the Control Budget and Control Schedule, thus it must be organized to advise and assist in any matter involving either. On a routine basis, the project controls staff will prepare status reports for both contractor and owner. The staff also will continually monitor project status for the purposes of identifying unfavorable conditions or trends, preparing appropriate recommendations for project management to control or eliminate negative deviations in cost or schedule, or to capitalize on favorable trends.

3. BASELINES FOR CONTROL

References 2 and 3 explain the use of both a Cost Breakdown Structure (CBS) and a Work Breakdown Structure (WBS) in the planning and controlling of construction. The CBS is a breakdown of all cost elements within a total project, both direct and indirect. The WBS is a part of the CBS, but includes only those CBS elements against which progress is tracked.

Once engineering design is complete, major equipment and bulk material quantities will have been established so cost control in the field concentrates on control of field labor unit costs, labor productivity, and overheads. Schedule control, however, considers all material items since their timely delivery is essential to avoid schedule delays and productivity problems associated with material shortages.

Budgets

Cost Control vs. Cost Accounting. Cost control is obviously important on any project. It is appropriate here to distinguish between cost accounting and cost control. Cost accounting is concerned with tracking receipts and expenditures of importance to good bookkeeping and accepted accounting practice. The structure for such accounting must be in accordance with accepted rules of accounting and serve whatever requirements there may be that relate to contract payment provisions, taxation, regulation, or project capitalization. Cost accounting also will reflect the pricing of a contract which may differ significantly from its costing (because of unbalancing and the tracking of indirect accounts such as profit and distributables). Field construction managers are concerned with cost - what specific operations should and do cost. The structure they will use for this control is the CBS, one level of which will contain the Control Accounts. These are the accounts against which actual costs are collected and compared to those budgeted. They are often at a more summary level than the crew reporting level. The CBS seldom will have the same structure as that used for cost accounting.

Cost control should be approached as an application of Pareto's Law, which essentially states that 80 percent of the outcome of a project is determined by only 20 percent of the included elements. Thus in establishing a cost control system, the idea is to isolate and control in detail those elements with the greatest potential impact on final cost, with only summary level control on the remaining elements. The greatest variable in the final cost of a construction project is usually the labor cost. Most of the other cost elements in the project (materials, equipment, and overhead) can be predicted or established with reasonable accuracy if the project is properly planned and estimated. Labor cost is a function of worker hourly cost, worker productivity, and use of overtime. The hourly rates are relatively easy to predict; it is productivity that is the real variable. Thus, a contractor will want to monitor worker hours expended and productivity as major elements in the cost control program. Of course, quantity control will be an included element as a basis for progress reporting as well as estimate verification.

Budget Baselines. The budget baselines for a project are generated through the estimating process. Whether or not the design documents are complete, planners must develop a cost estimate for the project. If the project has yet to be fully defined, this estimate is approximate and subject to some variation. As the project becomes better defined, the estimates are updated to reflect the new information.

For a fixed-price project, good estimating is critical because the estimate establishes the costs of all direct work as well as the total contract price which incorporates all elements of direct cost plus field overhead, contingency, general overhead, and a reasonable profit. The estimate also provides all quantity, cost, and productivity targets to be used for detailed control. As explained in Reference 2, the estimate will have been prepared using the same WBS as that used for the Control Schedule. This directly enables the production of quantity, cost, and productivity targets for each control work package.

Schedules

Steps in Schedule Development. Reference 2, in its description of the planning sequence for a fixed-price construction contract, explains the development of the WBS and the Initial Control Schedule. The technique is applicable to any contractual form and is summarized as follows:

> **Expand the WBS for Scheduling.** This involves dividing up the project into controllable parts suitable for schedule control; these parts are converted into schedule activities, where one or more activities comprise one element of the WBS. The level of detail possible is strictly a function of the level of project definition at the time it is developed. If the contract is of a reimbursable form and the project only partially defined, the WBS will be summary in level; if complete plans and specifications are available, it can be detailed.
>
> **Develop the Logic Diagram.** If the project definition is complete enough to permit development of a detailed WBS, it is then possible to develop a schedule in Critical Path Method (CPM) format. The first step in doing this is to develop the logic diagram. This is done by

taking the schedule activities and arraying them in Arrow Diagram Method (ADM) or Precedence Diagram Method (PDM) format to show their sequencing and relationships. On larger projects, separate logic diagrams for each area or system should be developed, analyzed individually, and then tied together. The logic diagram contains no durations.

Assign Durations to Activities. Each of the activities (and constraints on a PDM diagram) are assigned a duration. The duration may be a product of the estimating process or may be developed through consensus among the project team planners.

Assign Constraining Dates or Milestones. On most contracts, a contractor's schedule will be influenced by activities under the control of others. Typical examples are delivery of drawings, delivery of owner furnished equipment, or completion of work by other contractors. Reference 3 provides details on the establishment of these dates on an engineering-procurement-construction project. Normally, the contract documents will provide dates relating to these activities so that the contractor can assign those dates as constraining events in the schedule. Of course, the contractor may find that lead times for purchase of contractor-furnished materials or other conditions will establish additional constraining dates.

Enter Resource Requirements. The key resource requirements, particularly labor, critical materials, and major items of construction equipment, should be loaded into each schedule activity so that resource loading curves can be generated as a second product of the CPM schedule. Most CPM programs can "resource level" within available float to minimize resource requirement peaks and valleys.

Enter Resource Constraints. If limits are expected on the availability of labor, construction equipment, or other resource at any one time, these limits are entered into the program so that they can be considered by the CPM program when analyzing the schedule. Such constraints may force extension of some activity durations beyond those entered manually, and may force extension of the entire project.

Calculate Dates and Times. Once durations, logic relationships, and constraints have been assigned, the early and late dates and float durations may be calculated to create the CPM schedule.

Although the schedule may have been developed utilizing CPM, most construction personnel do not use the logic diagram format of the schedule thereafter as a control document. Instead, they will print out the schedule in either time-scaled logic diagram format, an equivalent barchart, or a tabular listing. Most modern project control computer programs can do this automatically. This approach utilizes the principles of CPM for schedule development while also exploiting the easier readability advantage of barcharts.

In developing the logic diagram and the schedule, schedule planners are cautioned against excessive detail. It requires the human mind and eye to verify schedule logic; the computer cannot do it. Thus, keep the detail to that which can be truly verified. As suggested previously, break the project into parts and develop a logic diagram for each part. Then, tie these together. In doing so, however, be extremely careful to not introduce false logic through these ties.

Once the schedule has been refined to the point that it meets all objectives, it becomes the Original Control Schedule for the project (sometimes referred to as the Baseline Schedule).

Hard and Soft Logic. In developing a critical path schedule, it is easy for a planner to constrain a project through introduction of arbitrary logic. For example, assume that four identical foundations (A, B, C, and D) are to be built. The planner may show them as being built in sequence, A through D, on the CPM. While that is perfectly logical, perhaps the field personnel would find it easier to build C first, B second, D third, and A fourth. What the planner has done is apply hard logic to a soft logic situation. Such actions compromise the value of CPM.

Planners must learn to handle soft logic items at a summary level so that field planners have the flexibility to do the work in the most efficient manner at that time. In the example above, instead of four activities with labels A through D on them, a single activity of "Four foundations, Area ___" should be used. The field planners could then determine the exact sequence when developing their working schedule.

Hard logic is defined as that which covers work involving well-defined activities that have fixed relationships. Soft logic covers work whose component activities are less defined and whose relationships are conditional. A typical hard logic item is the forming, reinforcing, placing, and finishing of concrete. Another is equipment assembly. Typical soft logic items are electrical tray and conduit installation, piping system erection, and wire pulling.

Integration of Procurement and Subcontracting. A project schedule should include all activities which may influence the project completion date. Since procurement activity definitely is a determinant of when work involving those materials or equipment can be accomplished, procurement lead times should be shown as schedule activities that begin when a requisition or purchase order is first initiated and terminate at delivery to the site. This delivery date is an event in the schedule which becomes a constraint for any activities requiring the materials or equipment on the purchase order.

Subcontractors are work activities equal with activities performed by the direct-hire work forces of the general contractor and will appear as separate activities on the project's Control Schedule. On the more complicated subcontracts, particularly those involving several interface points with other project activities, the general contractor will require the subcontractor to develop and present a detailed schedule for incorporation in the master Control Schedule. The general contractor must allow time for the solicitation-bidding-award-mobilization times for the subcontracts when developing the overall schedule.

Schedule Levels. The various participants in a construction contract have different levels of interest in the scheduling of the project. The owner and the contractor's home office are interested in summary level schedules. Project level personnel are interested in more detail. Thus, there are various schedule levels. While there is no universal agreement as to the number of schedule levels and their format, the following are representative.

Level 0 This is the total project and is, in effect, a single bar spanning the time from start to finish.

Level 1 This schedules the project by its major components. For example, a Level 1 schedule for a process plant may be divided into process area, storage and handling area, site and services, and utilities. It is shown in barchart format and may include key milestones.

Level 2 Each of the Level 1 components is further subdivided. For example, utility systems are broken down into water, electrical, gas, and sanitary. In most cases, this schedule level can be shown only in barchart format, although a barchart with key constraints may be possible. Milestones are normally included.

Level 3 The subdivision continues. This is probably the first level that a meaningful logic diagram can be developed. It is also a good level for the project's overall Control Schedule because it is neither too much of a summary nor too detailed.

Levels 4-X The subdivision continues to the level of detail needed by the user. When operating at these more detailed levels, the planner generally works with less than the total schedule. In most cases, these "look-ahead" schedules span periods of from 30-180 days. The user may utilize either barchart or CPM format for these schedules.

Figure 1 provides extracts from six levels of details of a process plant.

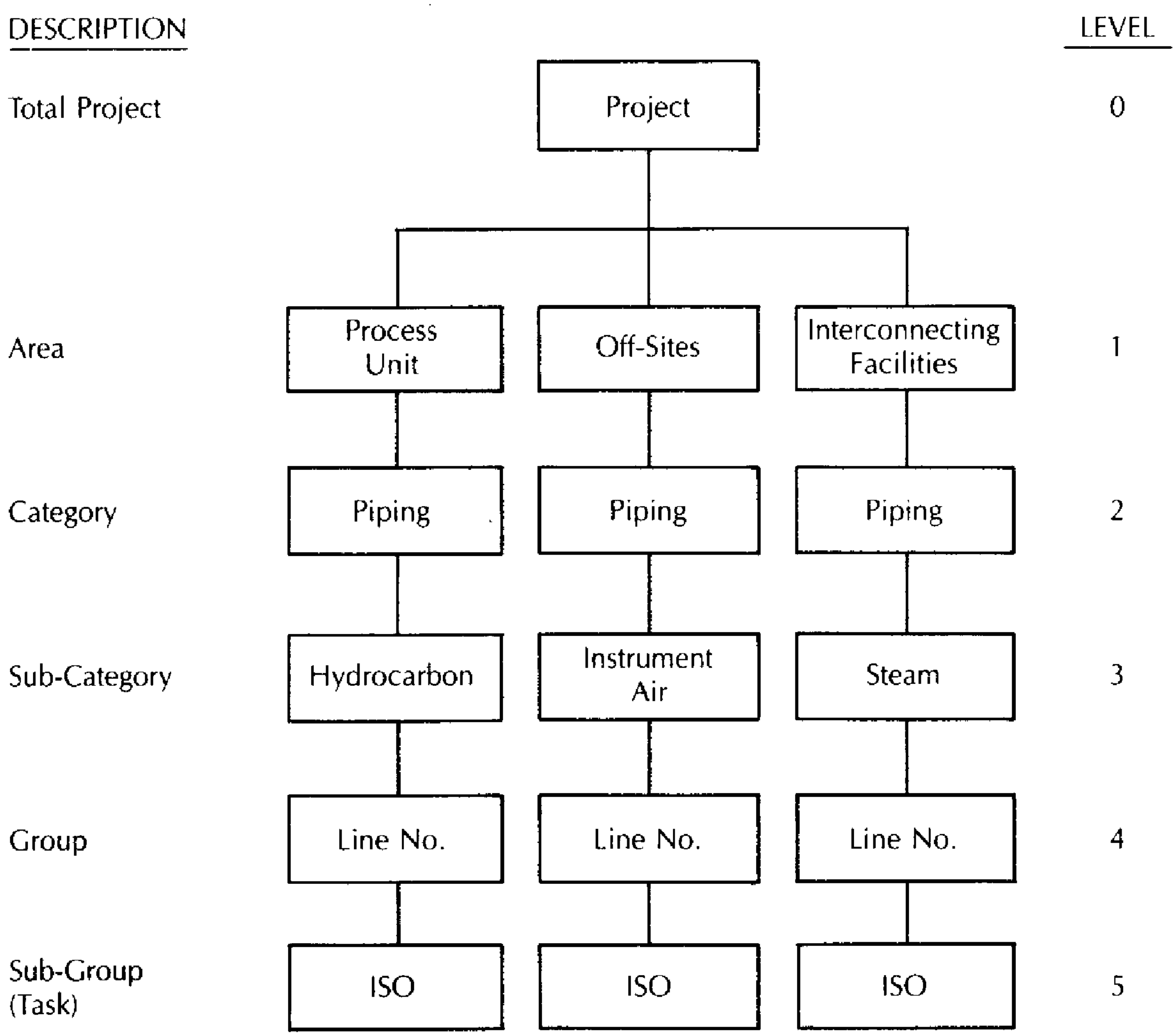

Figure 1. Piping Work Breakdown Structure

To illustrate how a planner moves from the control to the detailed level, reference is made to Figure 2. This figure is called a Control Account Baseline. It is a document which takes a Control Schedule work package (in this case Service Water Piping) and plans it out in detail. Note how the piping system is broken down into the work tasks required for its completion (large pipe, valves, etc.). These are then scheduled in barchart format. As is so often the case, these tasks are overlapping and there is some flexibility in their sequencing (soft logic). Use of the barchart format with float shown for each bar gives the field the flexibility it needs for accomplishing the work. Also, note from the other information included on the baseline that the document provides the basis for earned value control (see Chapter 4) and progress payments.

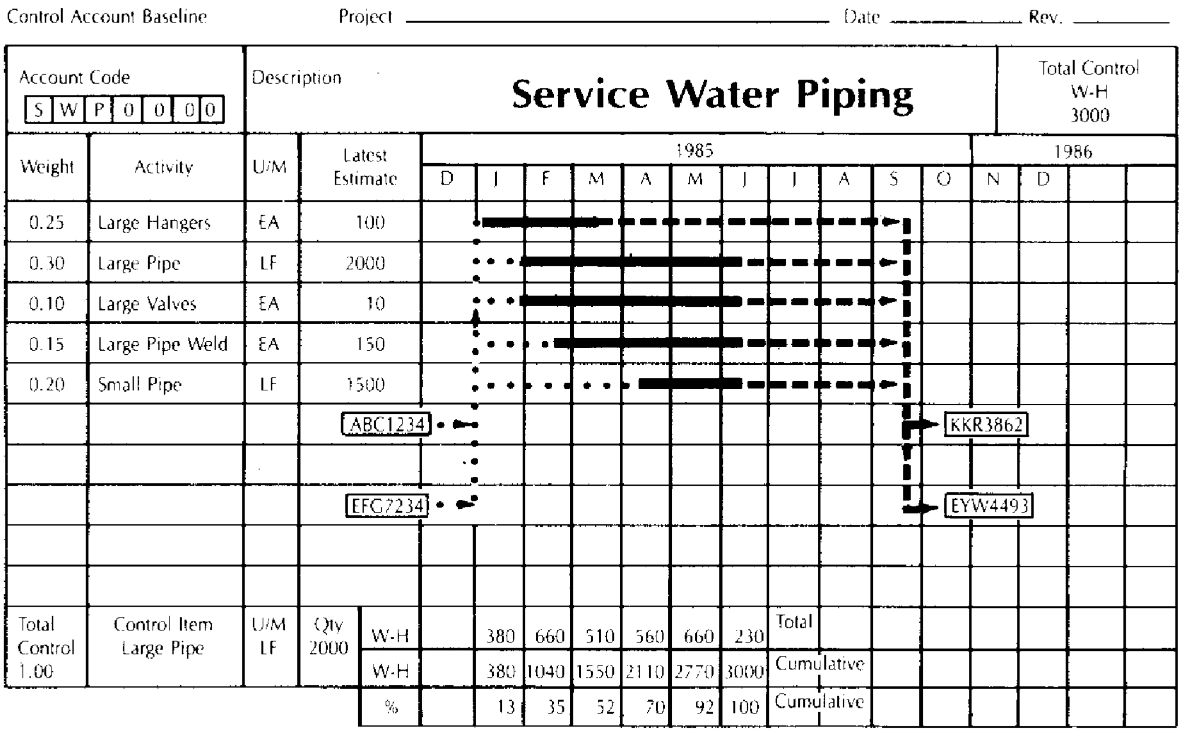

Figure 2. Control Account Baseline

Control vs. Working Schedule. A number of schedules will be utilized over the life of the project. When the project is first planned, the Original Control Schedule is developed. When an owner-approved change is received which changes the schedule, the Original Control Schedule is modified to create the Current Control Schedule. (A copy of the Original Control Schedule will be maintained for historical purposes.) The Current Control Schedule subsequently will be modified with each owner approved change. Reporting of ahead or behind status is always based on a comparison to this Current Control Schedule. Some owners may also require reporting of ahead or behind status against the Original Control Schedule as well. None of the Control Schedules are changed to accommodate variances in field performance by the constructors - a Control Schedule remains a reference baseline.

Recognizing the field performance probably will differ from that planned, the project control engineer also will maintain working schedules. One of these is a Look-Ahead Schedule of from three to six months duration. It is based initially on the Original Control Schedule, but is modified at least monthly to reflect actual past performance and a more current look at the future. Thus it can differ significantly from the Current Control Schedule, although the latter schedule remains the objective. Another working schedule is what might be called Plan of the Week, described in Chapter 6. Working schedules are at levels more detailed than that of the Control Schedule.

Other Schedules. A number of satellite schedules will be utilized in support of the Control Schedule. Typical schedules are those for subcontracting, rigging, equipment purchase, and material purchase. These are normally maintained in tabular form.

Code Structures

As described previously, various frameworks are established for control of the project. Within these frameworks a great deal of data will be received, stored, and processed, usually with the help of a computer that has database management capability. This requires the establishment of a coding structure that is standard for the project. Several account structures actually are required, and are used in various combinations to achieve the control integration needed. One describes the WBS and CBS and should be hierarchical in format to permit expansion to various levels of detail and the summarization of data at any level. Another structure catalogs generic activities or functions (such as placing concrete, slab on grade, with a crane and bucket). This is used in the cataloging of data in the historical database, for estimate breakdowns, and for recovery of data from the project for addition to the historical database. A third structure is used for the resources of construction - personnel, materials, and equipment - and finds application in resource loading of schedules, requisitioning, and reporting. Still other structures are used to code drawings, specifications, and purchase orders.

4. STATUS EVALUATION AND CONTROL

Measuring Work Progress

The work tasks required to complete a construction project vary from those required to clear and grade a site to the start-up and turnover of the completed facility. During the course of the project, those executing the construction will need to report periodically on the progress of each task. Six methods are described below for measuring this progress. All may find use on a given project.

The U.S. Departments of Defense (DOD) and Energy (DOE) have established what is known as the Cost and Schedule Control Systems Criteria (C/SCSC) for control of selected federal projects. While intended primarily for high-value, cost-reimbursable research and development projects, it may be applied to selected construction projects. This system is described in detail in Reference 5. Included within C/SCSC are various methods for measuring status; also, several terms are presented which have found some common usage within the construction industry. Certain useful features of C/SCSC have been incorporated within the system described in this publication.

Method 1: Units Completed. This method is applicable to those tasks which involve repeated production of easily measured pieces of work, each piece requiring approximately the same amount of effort. Usually there is no included mix of subtasks; if there is a mix, these are accomplished simultaneously and one of the subtasks can be used as the reference task.

Wire pulling is a task whose accomplishment is easily measured in terms of units of length of wire pulled and a task for which the Units Completed method is applicable. For example, if 10,000 LF of wire is to be pulled and 4,000 LF has been pulled, the percent complete is found by dividing 4,000 LF by 10,000 LF to show 40 percent complete.

Placing and finishing of a reinforced concrete slab is a type of work with multiple tasks handled simultaneously (placing and finishing), but progress may be reported on the basis of volume of concrete placed and finished or upon area of finished surface.

Method 2: Incremental Milestone. This method is applicable to any control account which includes subtasks that must be handled in sequence. For example, the installation of a major vessel in an industrial facility includes the sequential tasks or operations listed below. Completion of any subtask or operation is considered to be a milestone, which when completed represents a certain percentage of the total installation. The percentage chosen to represent each milestone is normally based on the number of work-hours estimated to be required to that point in relation to the total. In the listing below, the attainment of each milestone has been judged to be equivalent to having completed the percentage listed of the total installation:

Received and inspected	**15%**
Setting complete	**35%**
Alignment complete	**50%**
Internals installed	**75%**
Testing complete	**90%**
Accepted by owner	**100%**

Method 3: Start/Finish. This method is applicable to those tasks which lack readily definable intermediate milestones and/or the effort/time required is difficult to estimate. Millwright work is often in this category. For example, alignment of a major fan and motor may take from a few hours to a few days depending upon the situation. Workers know when this work starts and when it is finished, but never know the percentage completion in between. Other examples include planning activities, flushing and cleaning, testing, and major rigging operations.

With the Start/Finish approach, one arbitrarily assigns a percent complete to the start of a task with 100 percent being recorded when it is finished. A starting percentage of 50 percent is equivalent to a task completed at a constant rate over time and is reasonable for fairly short duration, lower value tasks. For longer or higher value tasks, a contractor would probably have to use something less (20-30 percent), primarily because an owner will hesitate to recognize too much completion in advance since it directly affects progress payments. For very short tasks, the start finish percentages are usually 0 percent/100 percent.

Method 4: Supervisor Opinion. This is a subjective approach and should be used only for relatively minor tasks where development of a more discrete method cannot be used. Painting, dewatering, constructing support facilities, installing architectural trim, and landscaping are candidates for this approach.

Method 5: Cost Ratio. This method is applicable to tasks such as project management, quality assurance, contract administration, and project controls. These tasks involve a long period of time or are continuous over the life of a project, and are estimated and budgeted on bulk allocations of dollars and work-hours rather than on the basis of production.

With this method, percent complete is found as follows:

$$\textbf{Percent Complete} = \frac{\textbf{Actual cost or work-hours to date}}{\textbf{Forecast at completion}}$$

Method 6: Weighted or Equivalent Units. This method is applicable where the task being controlled is a major effort involving a long period of time and is composed of two or more overlapping subtasks, each with a different unit of work measurement.

Structural steel erection provides a good example for application of this method. Structural steel normally is estimated and controlled using tons of steel components as the unit of measure. As illustrated in the listing below of subtasks included in steel erection, however, each subtask has a different unit of measure. In such a case, each subtask is weighted according to the estimated level of effort (usually work-hours) that will be dedicated to that subtask. As quantities of work are completed for each subtask, these quantities are converted into equivalent tons and the percent complete calculated as illustrated. The weighting may be changed during the course of a task's completion to reflect quantity or unit rate variances within subtasks. If this is done, it is important that the earned values be recalculated for all subtasks (see following section for earned value principles).

Wt.	Subtask	U/M	Quan Total	Equiv Steel Ton	Quantity To-date	Earned Tons*
0.02	Run foundation bolts	each	200	10.4	200	10.4
0.02	Shim	%	100	10.4	100	10.4
0.05	Shakeout	%	100	26.0	100	26.0
0.06	Columns	each	84	31.2	74	27.5
0.10	Beams	each	859	52.0	0	0.0
0.11	Cross-braces	each	837	57.2	0	0.0
0.20	Girts & sag rods	bay	38	104.0	0	0.0
0.09	Plumb & align	%	100	46.8	5	2.3
0.30	Connections	each	2977	156.0	74	3.9
0.05	Punchlist	%	100	26.0	0	0.0
1.00	STEEL	TON		520.0		80.5

$$\textbf{* Earned tons to date} = \frac{\textbf{(Quantity to date)(Relative weight)(520 tons)}}{\textbf{(Total quantity)}}$$

$$\textbf{Percent complete} = \frac{\textbf{80.5 tons}}{\textbf{520 tons}} = \textbf{15.5\%}$$

A variation of this approach utilizes equivalent units for each subtask. In the example above, each subtask item would be given a unit of measure that is an equivalent ton. For example, each beam would have an equivalent ton equal to:

$$\textbf{Beam Equivalent Ton} = \frac{\textbf{(.11 weighting factor)(520 tons)}}{\textbf{(859 beams)}} = \textbf{.0666}$$

Earned Value - General

As noted in the previous discussion, there can be many types of work and numerous ways of measuring progress on work. Having outlined methods for determining progress on a single type of work, the next challenge is to develop a method both for determining overall percent complete of a combination of unlike work tasks or a complete project, and for performing other evaluations of status. A system for accomplishing these is called Earned Value, although the terms Achieved Value and Accomplished Value occasionally are used.

Earned Value is keyed to the budget, which is expressed in both workhours and dollars (work-hours and dollars are the only common denominators for the many accounts within a project). Earned value can be applied to both direct and indirect accounts. However, most contractors use it only on those accounts that are utilized in progress control. Work-hour budgets are used as the basis. Some government contracts require its use on all accounts and the use of dollar budgets as the basis (see Reference 5).

Of the two systems for earned value application, one utilizes a fixed budget approach, the other a variable budget approach.

Earned Value - Fixed Budget System

Applicability. With this system, it is assumed that a fixed control budget has been established for the project, and that budget has been distributed among the project's included accounts. Such is the situation with fixed-price or target price contracts.

The System. To use the system for a single account, a direct relationship is established between percent complete of an account and the budget for that account. This relationship is expressed in this equation:

Earned Value = (Percent complete) x (Budget for that account)

As seen in this equation, a budgeted amount is "earned" as a task is completed up to the total amount in that account. One cannot earn more than has been budgeted. For example, assume that $10,000 and 60 workhours have been budgeted for a given account, and that account is now 25 percent complete as measured by one of the methods previously described. That means that $2,500 and 15 work-hours have been earned to date.

Since progress in all accounts can be reduced to earned work-hours (EWH) and dollars as explained, this provides a method for summarizing multiple accounts and calculating overall progress. The formula for this is:

$$\textbf{Percent Complete} = \frac{\textbf{(Earned work-hours/dollars all accounts)}}{\textbf{(Budgeted work-hours/dollars all accounts)}}$$

Cost and Schedule Performance. The concepts discussed thus far provide a system for determining percent complete of single work tasks or combinations of tasks. The next challenge is to analyze the results for the purpose of determining how well work is proceeding as compared to what was planned. Fortunately, the earned value system lends itself well to this challenge.

Only budgeted and earned work-hours and dollars have been identified to this point. To these must be added actual work-hours or dollars. These three categories provide the combinations needed for analysis. This can be most easily explained if one defines each of these terms in the following way:

- Budgeted work-hours or dollars to date represent what you plan to do. Under C/SCSC this is called Budgeted Cost for Work Scheduled (BCWS).

- Earned work-hours or dollars to date represent what you did. Under C/SCSC this is called Budgeted Cost for Work Performed (BCWP).

- Actual work-hours or dollars to date represent what you have paid for. Under C/SCSC this is called Actual Cost of Work Performed (ACWP).

Performance against schedule is then simply a comparison of what you planned to do against what you did. In other words, compare budgeted and earned work-hours. If budgeted work-hours are less than earned, it means you did more than planned and may be ahead of schedule. The reverse would probably mean you are behind schedule.

Performance against budget is measured by comparing what you did to what you have paid for. To do this, compare earned to actual work-hours or cost. If you paid for more than you did, you have overrun the budget.

The above can be expressed in the formulas below:

$$\text{Schedule Variance (SV)} = (\text{Earned work-hours or dollars}) - (\text{Budgeted work-hours or dollars})$$

$$= \text{BCWP} - \text{BCWS}$$

$$\text{Schedule Performance Index (SPI)} = \frac{(\text{Earned work-hours or dollars to date})}{(\text{Budgeted work-hours or dollars to date})}$$

$$= \frac{\text{BCWP}}{\text{BCWS}}$$

$$\text{Cost Variance (CV)} = (\text{Earned work-hours or dollars}) - (\text{Actual work-hours or dollars})$$

$$= \text{BCWP} - \text{ACWP}$$

$$\text{Cost Performance Index (CPI)} = \frac{(\text{Earned work-hours or dollars to date})}{(\text{Actual work-hours or dollars to date})}$$

$$= \frac{\text{BCWP}}{\text{ACWP}}$$

It should be noted that a positive variance and an index of 1.0 or greater is favorable performance.

Productivity Analysis. Project managers are always interested in knowing how well actual productivity compares with that used in planning and budgeting the work. While a comparison of earned to actual work-hours under the fixed-budget system may appear to provide an evaluation of productivity, it does so only if actual quantities of work exactly equal those budgeted for. This is not necessarily true, and therefore another mechanism is needed to evaluate productivity. It utilizes Credit Work-Hours.

Credit Work-Hours (CWH), like Earned Work-Hours (EWH), are derived quantities. CWH provides a vehicle for handling work quantity variations between budgeted and actual without distorting crew productivity figures. CWH is equal to the budgeted productivity work-hour unit rate (WH/unit) for a given task multiplied by the number of units completed. Since the actual units of work in a work package may vary from the budgeted (estimated) number of units, CWH may vary either way from EWH in a given work package. CWH are equal to EWH only if budgeted and actual quantities of work are equal. A productivity index may be calculated for a single work package or a combination of work packages (or the total project) using this formula:

$$\text{Productivity Index (PI)} = \frac{(\text{Sum of Credit Work-Hours})}{(\text{Sum of Actual Work-Hours})}$$

Example Using Fixed-Budget System. On a fixed-price project, a work package was estimated to include 200 units of work. Work was budgeted at 4 WH/unit. It was later learned that there were 240 units of work because of an estimating error. At the end of the latest reporting period, work was 50 percent complete (120 units) and 432 WH had been paid. Is this package overrunning or underrunning cost and is productivity better or worse than planned?

Work-hour budget = (200 units) x (4WH/unit) = 800 work-hours

Earned work-hours = (50% complete)x(800 work-hours) = 400

CPI = 400 EWH / 432 AWH = 0.93 **OVERRUNNING COST!!**

$$PI = \frac{CWH}{AWH} = \frac{(120 \text{ units}) \times (4WH/unit)}{432 \text{ AWH}} = 1.11$$

PRODUCTIVITY BETTER THAN PLANNED!!

Cautionary Notes. The Fixed-Budget System depends for its accuracy in summary level percent complete calculations upon the distribution of the total budget among included accounts in proportion to the work-hours involved. Should the initial distribution prove faulty as a result of significant work quantity variations or unrealistic productivity assumptions, the contractor should redistribute the total available budget to properly reflect currently recognized work requirements. Of course, the contractor cannot exceed the total available budget (including approved changes) in this redistribution, and in the case of an underbudgeted project, each account will be proportionately underbudgeted. Ideally, a contractor will have established a contingency account during project planning and budgeting from which coverage can be drawn for underbudgeted accounts or to which budgets can be transferred from overbudgeted accounts.

A precautionary note on summation of earned work-hours (or dollars) is appropriate under this system. It is entirely possible for the EWH in an account to be reduced from that credited in a prior reporting period. This is possible in at least two ways: (1) if some in-place work is subsequently rejected and must be redone; or (2) if suddenly it is discovered that the quantity of work included is greater than budgeted and this variation is not due to an approved change. For this reason, it is important when setting up databases and algorithms for manipulating this data that EWH not be summed by adding those earned during the current period to those accumulated during prior periods. Instead, calculations should be made for each account based on percent complete times budget and the totals generated by added the EWH of all accounts to date in which hours or dollars have been earned.

Earned Value - Variable Budget System

Applicability. This system is particularly suited for a project which is initiated on the basis of incomplete definition and which has its budget subject to considerable variation as a consequence. Thus, whereas the Fixed-Budget System was constrained by a fixed budget for the total project, this system can take advantage of floating budgets. Most cost-reimbursable work would be controlled using the Variable Budget System.

The System. Each identified work package in the project is assigned a budget (work-hours or dollars) based on the best available work quantity information at that point in time. As each work package is fully defined, its budget is adjusted to reflect final work quantities. Of course, the Control Budget for the project is adjusted each time an included package is changed. These budgets are referred to as the Quantity Adjusted Budgets (QAB).

Cost and Schedule Performance. The methods for calculation of Percent Complete, SV, SPI, CV and CPI as described under the Fixed-Budget System are fully applicable to this system. Earned work-hours may be calculated by multiplying percent complete by the QAB, or for those activities tracked under the Units Completed method, by multiplying the units completed by the budgeted unit rate.

Productivity Analysis. Under this system, the CPI provides a direct evaluation of productivity performance since the QAB automatically accounts for quantity variations. There is no need for a separate calculation of a productivity index using Credit Work-Hours.

Cautionary Notes. Reimbursable projects in which construction commences before complete design drawings are available will tend to experience significant rework as a consequence of design change. Such rework increases the budgets of involved work packages. When determining percent complete, it would be wrong to include the reworked portion of these budgets or those hours earned when doing the replaced work in the calculations even though these are paid for by the client. To avoid this, it is necessary to purge such hours from the accounts as rework occurs. QABs and actual hours wasted as a result of rework should be transferred to separate accounts outside the basic control structure so that the accounts may later show the extent and cost of rework.

As with the Fixed Budget System, it is important when setting up databases and algorithms for manipulating data that EWH not be summed by adding those earned during the current period to those accumulated during prior periods. Instead, calculations should be made for each account and the totals generated by adding the EWH of all accounts to date in which hours or dollars have been earned.

Choosing a System: Fixed or Variable

The choice of a system to be used on a project is dictated in some cases by the project itself, in other cases by an option. On a project started on the basis of incomplete designs, the variable system should be used since it is the only one responsive to the inevitable quantity variations that come as the project is fully defined. On well-defined projects, a choice is made on the basis of characteristics desired in the control system.

The Fixed Budget System has these characteristics:

- Provides a direct evaluation of cost and schedule performance; requires supplementary system for productivity evaluation.

- More simplified bookkeeping; less potential for operator-caused errors.

- The fixed budgets provide a constant target for management to see. This is ideal for fixed-price work or other work with target budgets.

- Under this system, the CPI and PI are not necessarily the same. Having the two separate indices provides more tools for analysis.

- Performance data is susceptible to distortions if the project budget is not realistically distributed.

The Variable Budget System has these characteristics:

- Provides direct evaluation of productivity and schedule performance (CPI and PI are the same when using work-hours; also when using cost if there is no wage rate variance); requires supplementary system for evaluation of cost performance if operating against a fixed or target budget.

- Provides a moving budget that varies directly with actual quantities of work and budgeted productivity rates for included tasks. This is ideal for projects with open budgets. For fixed or target budget projects, a contingency account would be required to balance additions and deletions in the work accounts.

- Requires more operator attention to database management because of continually changing baseline information.

C/SCSC vs. Methods Proposed

Under C/SCSC, the CBS and WBS are one and the same and all accounts are based on dollars, not work-hours. Also, the overall cost and schedule status calculations combine both work and overhead accounts. This approach is well suited for complicated cost-reimbursable projects typical of many governmental R&D contracts, but is not well suited for industrial or building construction, particularly if fixed-price.

Use of dollars instead of work-hours as the basis tends to create a less responsive system for progress control because some cost data has built-in lags - the exact costs of some cost elements are not known until invoices are received. Also, inclusion of overhead accounts in progress calculations distorts the true picture of progress - one can be spending considerable money in overhead accounts while accomplishing little in the field. The construction field manager is concerned primarily with schedule performance and labor cost on a day-to-day basis. Work-hours are logged daily or weekly via time cards along with work quantities. With only this information, the project control engineer is able to provide the manager with what is needed most for responsive management - continuous, timely status information on percent completion, schedule performance, labor productivity, and labor cost. Certainly overall cost is important, and all costs eventually will be collected against the CBS and reflected in monthly project reports.

5. REPORTING AND ANALYSIS

Work & Cost Status

Having established the basis for control of the project, controllers are in a position to exercise that control. They will do this by receiving reports of actual progress and costs, and by comparing these to the plan via various reports.

Work Status. On the Control Account Baseline (Figure 2, Chapter 3), the progress measurement method is established under the Unit of Measure (U/M) column for each task. Tasks can then be rolled up using earned value to show the overall percent complete of the control account. Figure 3 is a representation of a reporting format using the Service Water Piping of Figure 2 as an example (Note: Figures 3-11 are at the end of this chapter). The many control accounts, in turn, can be summarized at various levels or for the whole project using earned value.

Cost Status. As mentioned previously, the contractor will be interested in the work-hour statistics for the project as a major cost tracking tool and will utilize the CPI and CV as indicators.

Cost in terms of dollars also will be statused. All costs will be charged to one account or other on the CBS. However, all costs attributable to a WBS work account are seldom charged along with the labor and major material items in that account. To do so involves excessive paperwork and does not significantly contribute to control. Instead, items such as construction equipment and tools, materials, and supplies expended in installing permanent materials more often are charged to project-wide accounts.

Tabular reports are appropriate for summarizing cost status in various ways. Typical summaries would be:

- A cost summary that shows for each account the original control workhours or dollars, current control work-hours or dollars, this period workhours or dollars, job-to-date work-hours or dollars, remaining to complete work-hours or dollars, forecast at completion work-hours or dollars, and variance.

- A labor rate report that shows for each craft and for each control account the original control figures for dollars, work-hours, and dollars per work-hour; and then provides for each category the current control, experience this period, job-to-date experience, forecast at completion, and variances.

Control Account Baseline   Project ________   Date ________   Rev. ________

Account Code		Description									This Period / To Date
S W P 0 0 0 0		**Service Water Piping**									
Weight	Activity	U/M	Latest Estimate	Week Ending 1/6	1/13	1/20	1/27				
0.25	Large Hangers	EA	100	5 / 5	15 / 20	15 / 35	15 / 50				
0.30	Large Pipe	LF	2000				50 / 50				
0.10	Large Valves	EA	10								
0.15	Large Pipe Weld	EA	150								
0.20	Small Pipe	LF	1500								
Total Control 1.00	Control Item Large Pipe	U/M LF	Control Quantity 2000	25 / 25	75 / 100	75 / 175	90 / 265				
			Field Engineer								

Figure 3. Monthly Quantity Report

(Note: This figure relates directly to Figure 2, Control Account Baseline)

Example Calculations, week ending 1/27:

Report shows: 15 large hangers installed that week for total of 50 to date
50 LF of large pipe installed that week for a total of 50 LF to date

Control item is Large Pipe; all items are converted to equivalent feet of that.

$$\text{Large hangers} = \frac{15 \text{ each}}{100 \text{ total}} (.25 \text{ weight})(2000 \text{ LF control quantity}) = 75 \text{ equiv. feet}$$

$$\text{Large pipe} = \frac{50 \text{ LF}}{2000 \text{ total}} (.30 \text{ weight})(2000 \text{ LF control quantity}) = 15 \text{ equiv. feet}$$

Total equivalent feet this period = 90

- A quantity and work-hour report which shows the original control work quantities, work-hours and the work-hours per unit of work for each control account; and then provides comparable information under the headings of current control, current period, job-to-date, and forecast at completion. This same report can show the earned work-hours this period, earned work-hours to date, and the labor CPI.

Schedule Status. A visual display of schedule status is best presented on a barchart representation of the schedule. A sample of an excellent format for summary level reporting to management is shown in Figure 4

Analysis, Trending, and Forecasting

While it is important to know the exact status of a project at any point in time, it is equally important to analyze the situation so that appropriate corrective action can be taken if needed. The following discussion provides example ways for analyzing, trending, and forecasting.

The Cost and Schedule Performance Curves. A good format for quickly showing the cost and schedule status of the project is shown in Figure 5. On this graph are plotted the planned budget cumulative expenditure curves (in terms of either dollars or work-hours) plus the cumulative actual and the cumulative earned to the date of the report. One can quickly see the cost variance and approximately how much the project may be behind or ahead of schedule.

Index Tracking. Figure 6 is an example graph for tracking indices of the types described in Chapter 4. Figure 6 tracks the Productivity Index. Note on this graph the use of a "Cumulative Plan" curve, which does not coincide with the 1.0 datum line. This curve recognizes that productivity for this work usually can be expected to be lower during the early stages of a project, reach a peak about midway, and then decrease toward closeout (actual shape must be based on experience). Having done this, the actual productivity plot can be more meaningfully evaluated. As shown on the example chart, a productivity index of 1.06, which one normally assumes is favorable, is actually low compared to what it should be for that point in time.

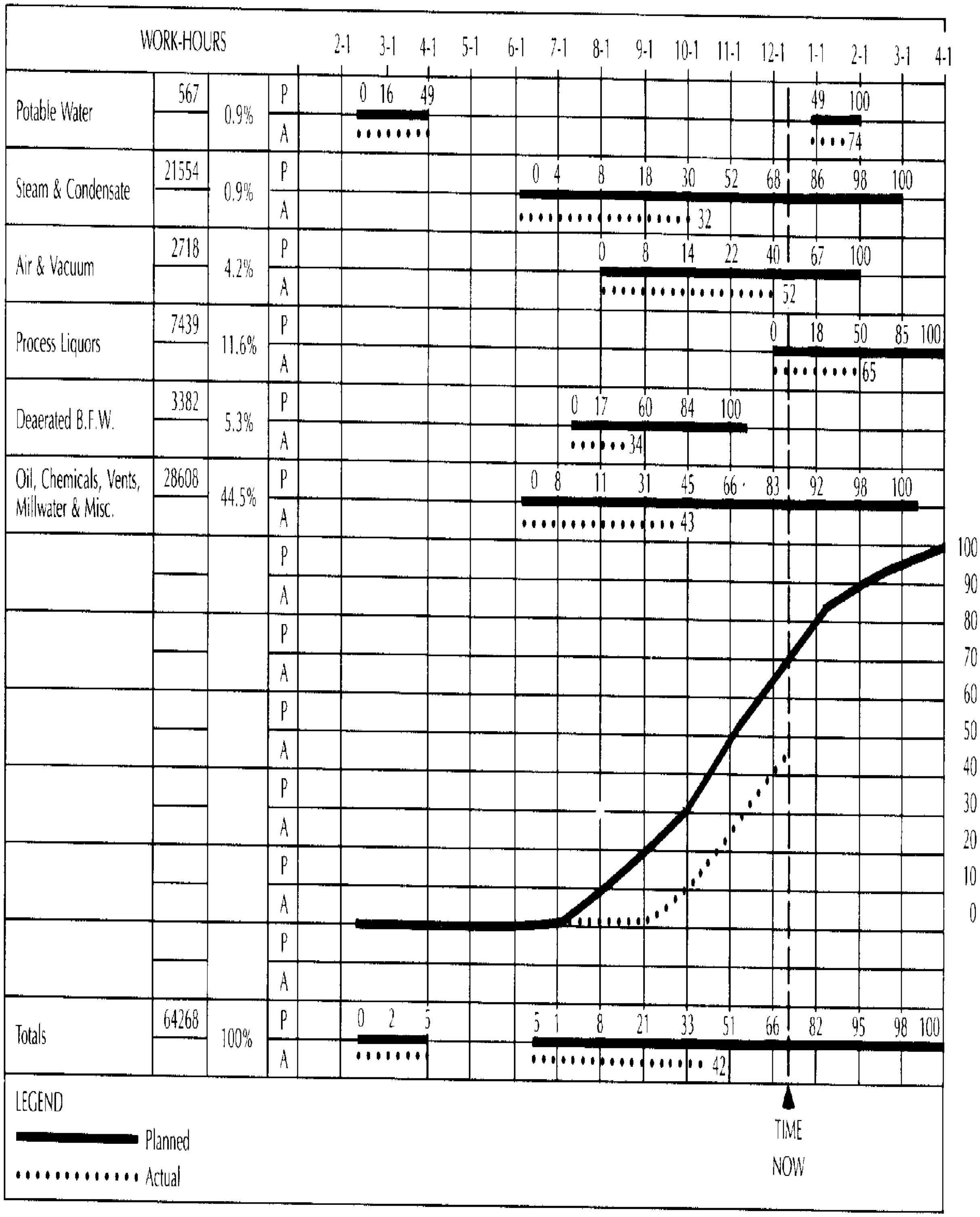

Figure 4. Monitoring Schedule

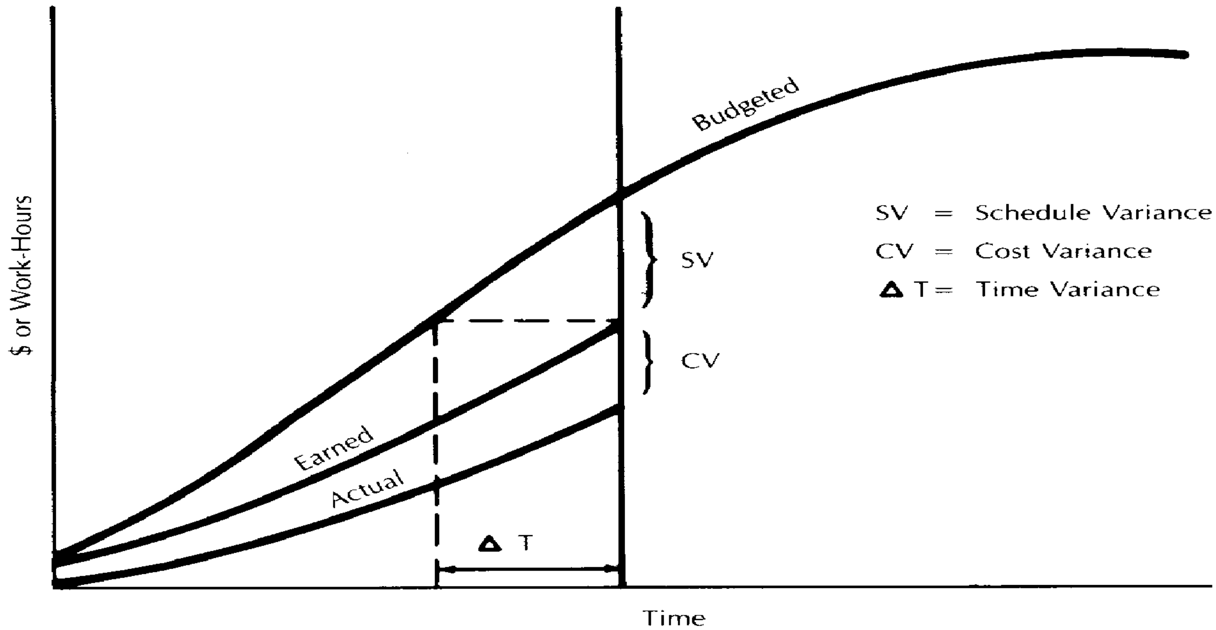

Figure 5. Cost and Schedule Performance Graph

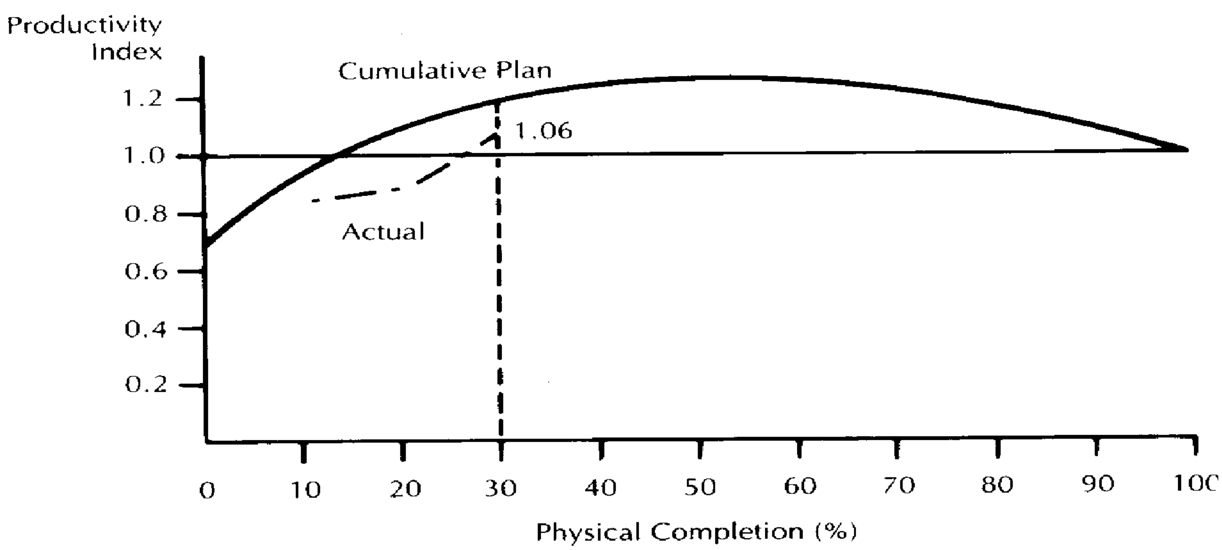

Figure 6. Productivity Profile

Other Tracking. Figure 7 is an interesting variation of Figure 6. Note how the vertical axis is work-hours per percent complete. As a result, the Cumulative Plan Curve is an inverted image of the projected curve in Figure 6. This graph also includes the Plan for Period and Actual Period plots to give it more usability. Note how the point identified as "(1)" shows that actual period performance equals that of planned performance. When one looks at the actual cumulative performance, however, it can be seen that the project still has a problem because of the poor performance of prior periods. Therefore, performance must become better than planned if the project is to recover.

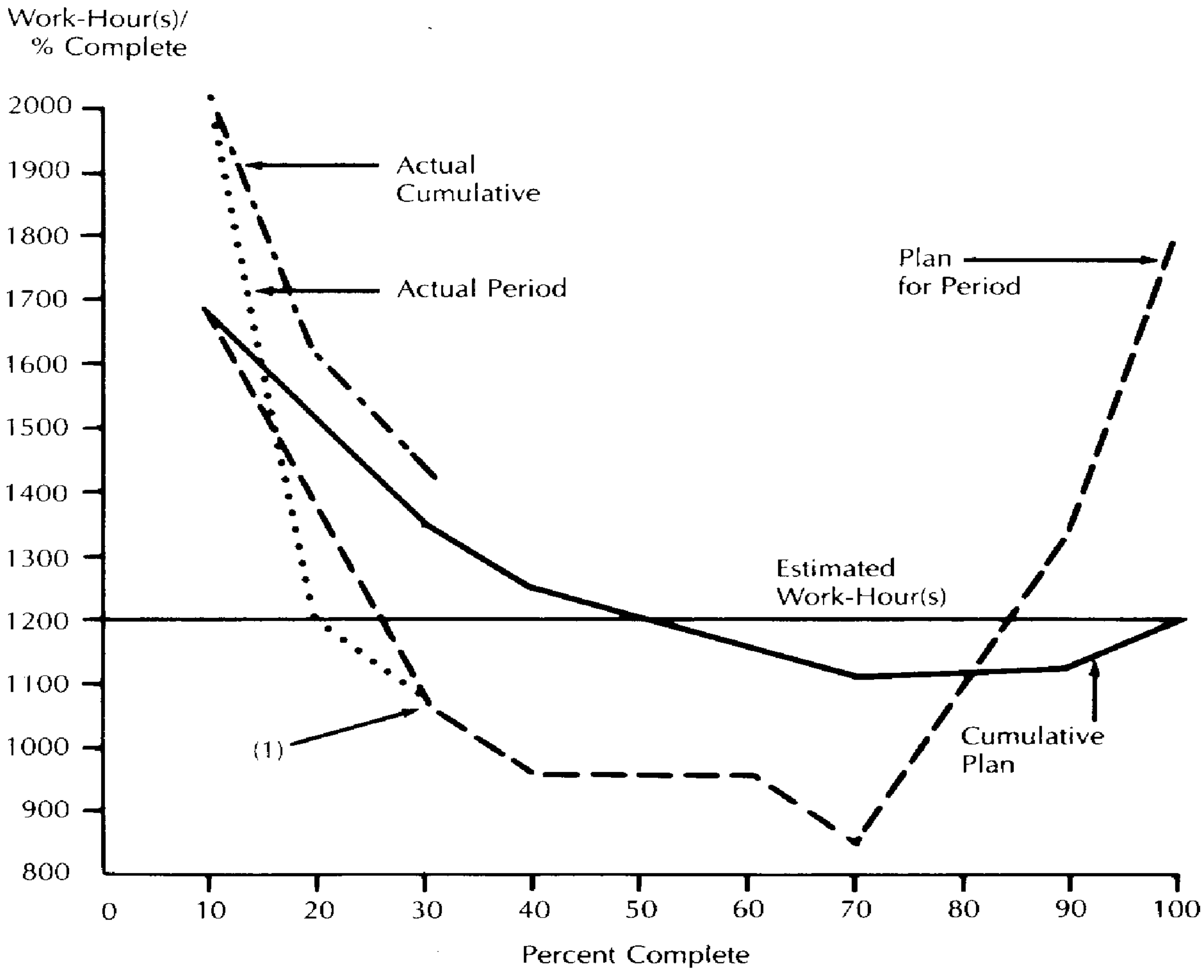

Figure 7. Work-Hour Productivity Trend Chart

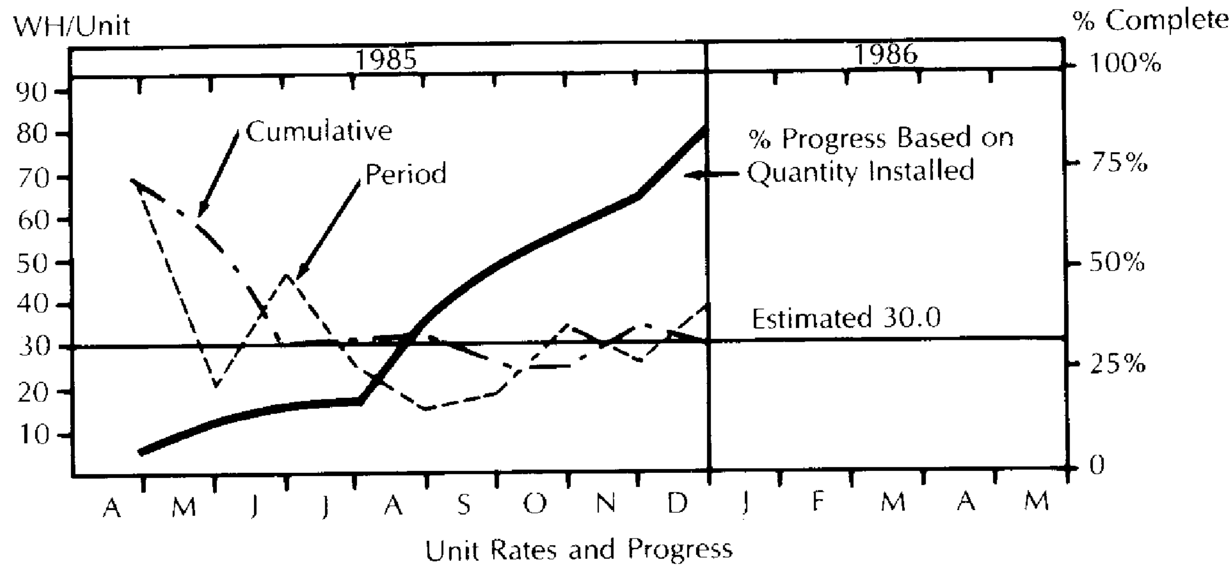

Figure 8. Building Structural Steel Erection

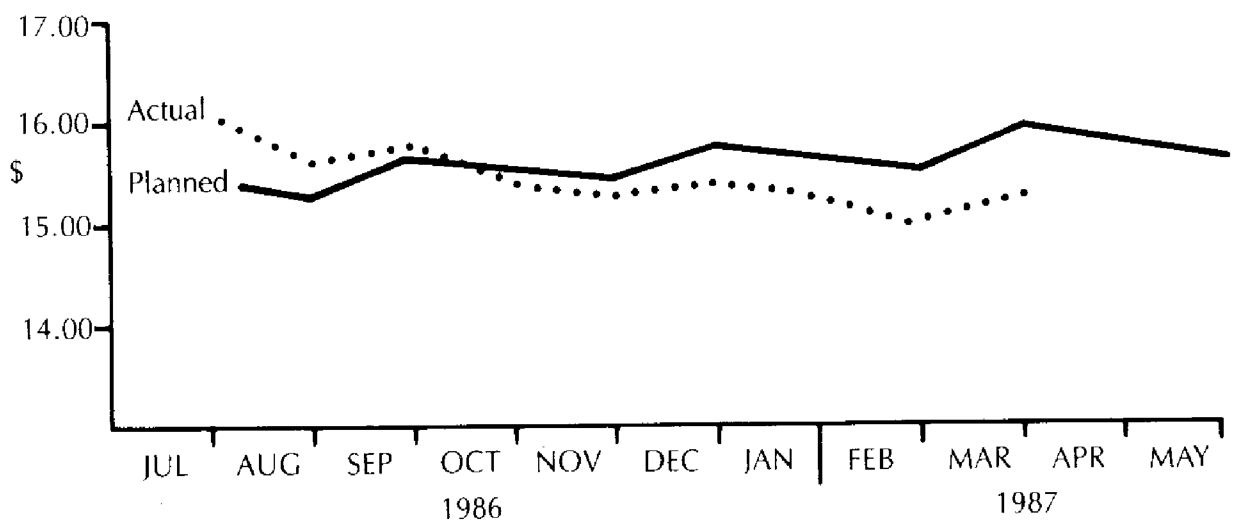

Figure 9. Unit Wage Rate

Figure 10 is representative of a format for tracking bulk quantity items, for example wire pulling and terminations. The two solid curves shown represent the plan. By superimposing actual performance thereon (dashed curves), the situation and trends are readily shown.

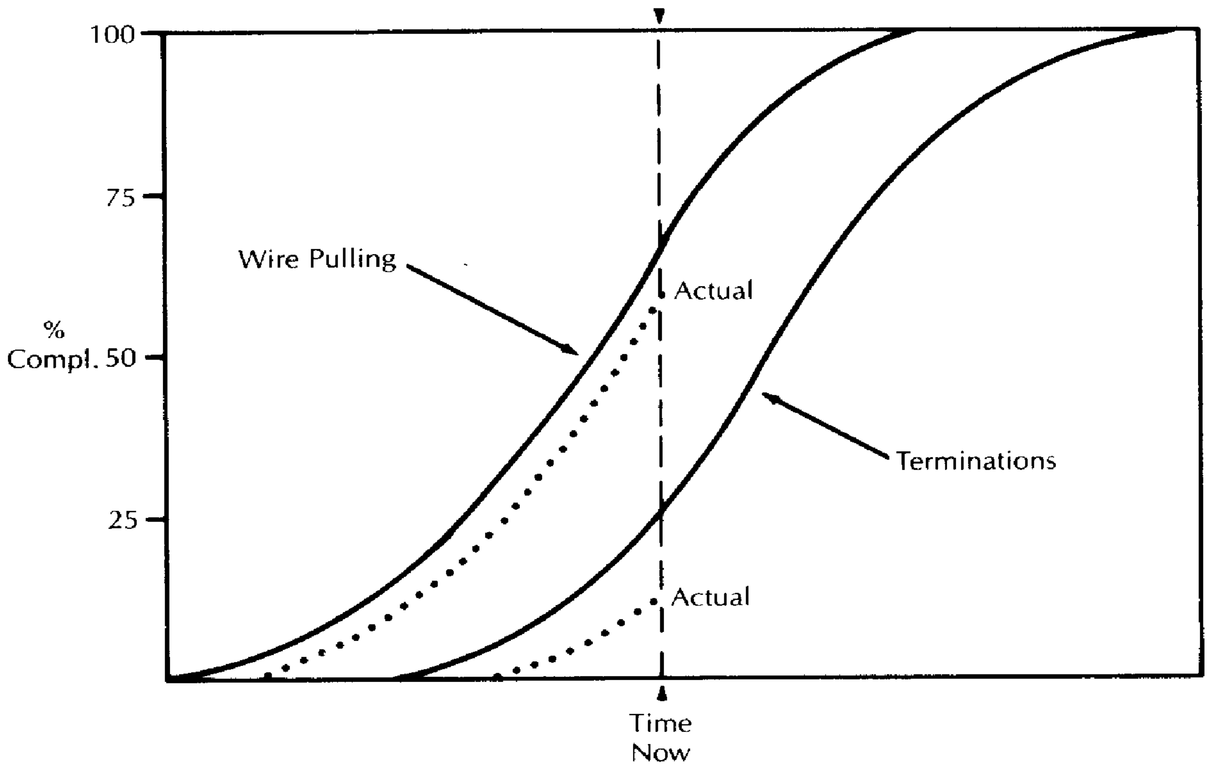

Figure 10. Bulk Quantity Curves

Analysis Techniques. Each report item has significance in itself, but it usually takes a combination of items for the total situation to be shown. For example, labor cost performance (CPI less than 1.0) is certainly a problem, but the CPI does not point to the cause of that problem - it could be any combination of low productivity, bad quantity estimate, excessive manning, or higher crew wages. Thus, report data must be available in each of those areas to enable the manager to isolate the problem and take remedial action.

Figure 11 is an analysis tree involving just two report items - SPI and Total Float. Note the many possible combinations here. Other analysis trees using other report items are readily developed.

TF > 0	SPI > 1.0	AHEAD OF SCHEDULE ON CRITICAL PATH; MORE WORK BEING DONE THAN PLANNED
	SPI = 1.0	AHEAD OF SCHEDULE ON CRITICAL PATH; SOME SHORTFALL IN WORK ON NON-CRITICAL ACTIVITIES
	SPI < 1.0	AHEAD OF SCHEDULE ON CRITICAL PATH; SIGNIFICANT SHORTFALL IN WORK ON NON-CRITICAL ACTIVITIES
TF = 0	SPI > 1.0	CRITICAL PATH ON SCHEDULE; MORE WORK BEING DONE ON NON-CRITICAL ACTIVITIES THAN PLANNED
	SPI = 1.0	CRITICAL PATH ON SCHEDULE; TOTAL WORK VOLUME IS AS PLANNED
	SPI < 1.0	CRITICAL PATH ON SCHEDULE; SHORTFALL IN WORK ON NON-CRITICAL ACTIVITIES
TP < 0	SPI > 1.0	CRITICAL PATH ACTIVITIES BEHIND SCHEDULE; TOTAL WORK MORE THAN PLANNED INDICATING EXCESS ATTENTION TO NON-CRITICAL ACTIVITIES
	SPI = 1.0	CRITICAL PATH ACTIVITIES BEHIND SCHEDULE; TOTAL WORK VOLUME AS PLANNED MEANING TOO MUCH ATTENTION TO NON-CRITICAL ACTIVITIES
	SPI < 1.0	CRITICAL PATH ACTIVITIES BEHIND SCHEDULE; TOTAL WORK LESS THAN PLANNED; NEED MORE OVERALL EFFORT

Figure 11. Analysis Tree – Total Float and SPI

Forecasting

Sophisticated forecasting techniques are explained in management science texts, but few constructors are comfortable with them. One thing is certain, no two methods, sophisticated or otherwise, produce the same answer. Three basic approaches are provided here.

Method 1: This method is useful for forecasting costs and work-hours. It assumes that work from this point forward will progress at planned rates whether or not these rates have prevailed to this point. In formula form, it is:

$$FAC = (ACWP) + (BAC - BCWP)$$

where:
- FAC = Forecast At Completion ($ or WH)
- ACWP = Actual Cost of Work Performed to Date ($ or WH)
- BAC = Current Budget at Completion ($ or WH)
- BCWP = Budgeted Cost of Work Performed to Date ($ or WH)

Method 2: This method assumes that the rate of progress prevailing to date will continue to prevail. This is found through this formula:

$$FAC = (BAC) / (CPI)$$

where: CPI = Cost Performance Index
Other terms as above

Method 3: This method utilizes curves such as several of those included herein and is useful for forecasting any piece of data represented by those curves. The forecaster simply makes the best extrapolation possible using the typical shapes of such curves and other information that may be available to the forecaster to make the projection.

It is recommended that no single forecasting method be used. Rather, include a forecast by each of the above methods because these provide a range of possibilities.

Miscellaneous Reports

A number of other reports may be products of the project controls effort. Examples are:

Requisition/Purchase Order Status. A summary of active requisitions and purchase orders of major items to include emphasis on any variances between requested and projected delivery dates.

Materials Status. A report showing quantities on hand, on requisition, and other data relating to materials which are not stocked on an inventory level basis. This is particularly useful for weekly planning meetings.

Materials Exception Report. A listing of items which were reported to be in stock and available for issue, but which were not found at the time they were needed.

Vendor Drawing Status. A summary of vendor drawings due from engineering and their status with respect to plan.

Subcontract Status. A summary of planned and actual activity relating to the process of seeking and contracting with subcontractors.

Fabrication Status. A summary of planned and actual status of fabrication activity both off- and on-site.

Construction Equipment Status. A listing of major items of construction equipment and their status.

Critical Items Report. A listing of potentially adverse situations and all critical materials, equipment, or personnel whose availability when needed is currently uncertain. Includes a summary of expediting action taken or planned.

Quality Trends. A summary of statistics relating to quality such as cost of rework due to quality problems, defects and deviations noted, and others.

Overhead Trends. A summary of planned vs. actual data relating to overhead. Can be presented in terms of cost or numbers of people, for example, and is usually related to time.

Unscheduled Work. A summary of type of activity, number of workhours expended, and costs associated with unscheduled work.

Project Demographics. Summaries, in either tabular or graphic form, which show total project and individual craft population statistics (both estimated and actual) for each work day.

Labor Statistics. Summaries by craft to show crew mix ratios (e.g., helper, journeyman, foreman), planned and actual composite wage rates, absenteeism and turnover rates, late starts and early quits, and others during a reporting period.

6. IN-PROCESS MANAGEMENT

The Team Approach

Successful coordination of the many parties involved in a construction project requires a team approach to management. During the mobilization stage of a project and thereafter as new participants are added, the team atmosphere is established and strengthened through meetings. The first meetings are primarily for the purpose of assuring that all participants understand the contract and their roles, authorities, and coordinating responsibilities. It is during these meetings that problem areas are anticipated and solutions are offered. These meetings are a feature of proactive management and emphasize participation by all players.

Throughout the project's life, periodic and special meetings are held to review status and plan ahead. Weekly meetings will be required to plan work for the coming week. The Look-Ahead Schedule will be reviewed at least monthly. Special meetings will be called to resolve crises.

Materials Management

An important component of the total management system utilized on a project is the Materials Management System (MMS). Materials management is concerned with the total process of materials identification, ordering, vendor documents, fabrication, expediting, delivery, receipt and inspection, storage, and issue. As a consequence, the players in the process are many: engineers, purchasing agents, expeditors, quality inspectors, project control engineers, warehouse personnel, and foremen.

With so many players in the MMS, it is essential that their activities be coordinated and tracked. Thus, one individual on the staff should be designated as Materials Coordinator. This individual is to be the single source of information on all materials activity, and thus will serve as the eyes and ears of the project manager on this subject. The Materials Coordinator will require and maintain a variety of reports that provide the up-to-date status of all materials, and will be a key participant in all weekly planning meetings. The Materials Coordinator is logically assigned as a member of the Project Controls staff since materials tracking should be part of the project's integrated control system, which is managed by that staff.

Plan of the Week

The Look-Ahead Schedule described in Chapter 3 is based on the best planning information available at the time, but still contains uncertainties such as crew, materials, and equipment availability. The next step is to validate this schedule. To do this, each of the work packages in at least the first month of the Look-Ahead Schedule are examined in detail. For each work package, the crew, materials, special tools, and equipment requirements are identified for each estimated day of duration. This is done by the foreman most closely associated with that work. A listing of the material items and special tools is given to Materials Control, which is required to identify those items on hand or to provide information on their projected availability. This will produce a catalog of near-term work packages for which materials are expected to be available. Then during the weekly planning meetings, the various foremen and superintendents review those work packages which have the potential for starting. While keeping in mind the need to conform to the Look-Ahead Schedule as closely as possible, they balance crew, tools, and equipment availability with materials availability and produce the Plan of the Week. Once this is agreed to, Materials Control is requested to put the materials and tools for each work package on hold until authorized for release by the responsible foreman. Materials Control may be requested to pre-position items for crews each work day.

The above process has a number of advantages. First, it will stimulate any expediting action needed to make materials available. Second, it provides the best assurance of avoiding lost time through non-availability of tools, equipment, and materials. Finally, it is an excellent participative management technique that involves the field production personnel in the detailed planning of their work. This effectively commits them to the plan and is the best assurance that it will be carried out.

Owner Changes

On any project, the contractor should expect to receive owner-approved changes. Any fixed-price construction contract should contain a Changes Clause which establishes the owner's rights to make changes and the mechanism for accommodating them. Since any change whether additive or deductive constitutes a change in the scope of work, a change in the budget and/or schedule normally will be required. On a fixed-price contract, the amount of budget and schedule change is usually negotiated between owner and contractor based on a proposal submitted by the contractor. Once the budget and schedule changes are approved, the Current Control Budget and Current Control Schedule are revised to reflect them.

On a fixed-price contract, some changes to the scope of work may not he considered as changes within the meaning of the Changes Clause. A classic example is a piece of work overlooked by the contractor when bidding on the contract. Such work was part of the scope of work from the owner's viewpoint, even if not included in the contractor's plan and budget. Such changes must be reflected in the contractor's schedule. As for budgets, the contractor may want to redistribute available budgets to cover the omitted work. A contingency allowance included in the budget for this purpose is helpful in this case. In any event, the contractor can expect no money or time extension from the owner in this situation.

Budget Variance Management

The total budget for the project will be distributed over the CBS. Actual costs then will be recorded against these accounts so that cost control is possible, account by account. However, as pointed out in Chapter 5, the dollar figures only indicate whether an account is over, on, or below budget; it does not identify the source of any problem if there is one. In fact, as also pointed out in Chapter 5, a favorable variance in an account cannot be assumed to mean that all is well within the account - an unfavorable situation may be masked by a favorable one. For example, the costs in a work account are a function of the amount of work, the costs of materials and equipment, the wage scales of the workers, and worker productivity. A bad quantity estimate, higher than anticipated wage scales, higher materials costs, and poor productivity are all suspect in case of cost overruns. Thus, real budget control includes the use of indices, factors, and various charts of the type illustrated in Chapter 5 as tracking tools.

Schedule Variance Management

It is highly unlikely that actual progress will exactly mirror that planned on the Current Control Schedule. Despite this fact, and as explained in Chapter 3, the Current Control Schedule will remain the schedule goal for the project. If things are proceeding ahead of schedule, there is no problem unless one is forced into a holding pattern while awaiting material delivery or completion of work by others. Such a disruption with the attendant layoff and rehiring of personnel will affect worker morale and productivity, and should be avoided through better leveling of work leading to the constraining dates.

Falling behind schedule is another matter, particularly if it involves critical path activities, since the completion of the project by the target date becomes jeopardized. Managers then look for a means to compress the schedule. Schedule compression can be achieved by several methods, including the following:

Revise schedule logic. A complete review of the project's logic may reveal some artificial constraints, faulty logic, or excessive durations that had been included, which if corrected, could permit rescheduling of remaining work within remaining time.

Work methods analysis. Through time-lapse photography or other methods, study existing crew compositions and methods for accomplishing work for discovering more efficient, less time-consuming methods using other equipment, different crew compositions, revised work layout, or better work sequencing. For example, a night crew might be established to preposition all materials for a day crew so that the day crew does not consume so much time in materials handling.

Multiple shifting. If adequate skills are available, work may be scheduled over multiple shifts. This may cause some reduction in overall productivity because of overlap and coordination problems between shifts.

Overtime. Work selective overtime. This has the disadvantages of higher wage rates and potentially lowered productivity on an extended basis.

Materials substitution. If delays are being caused by lack of specified materials, it may be possible to substitute an acceptable, readily available item.

Bonus incentive program. Establish a one-time crew bonus for achieving a milestone date.

Value engineering. Although value engineering is primarily associated with the design engineering phase of a project, there may be some potential during the construction phase for changing the design of some project component which has yet to be constructed, the new design requiring less time for construction. For example, a cast-in-place wall might be changed to tilt up.

Constructability studies. These studies also have their greatest influence if conducted during design engineering, but still have potential during construction. For example, an item scheduled for field erection/assembly might be handled using off-site prefabrication with only final installation required at the site.

Additional suggestions are contained in the forthcoming CII publication, Schedule Compression.

If critical path activities are on schedule but there is less overall work being done than scheduled (i.e., not enough work is being done on noncritical activities), the field managers must hire additional crews or take whatever other action is appropriate to bring the level of non-critical work up to plan. Should this condition be allowed to continue, some non-critical activities will probably become critical and will only add to the schedule management problem.

Contingency Management

The construction planners hopefully have included within the project budget an amount for contingency, which will have been calculated using modern risk management techniques. Such an amount is to cover known items of risk (knowns), potential items (known unknowns), and unforeseen items (unknown unknowns). It is appropriate to have both a budget and a schedule contingency account.

Assigning responsibility for the usage of contingency funds must be established at the outset. With the amount of actual contingency spending a major concern, the movement of funds must be explicitly identified and controlled throughout the life of the project. Control is further enhanced by limiting the number of persons with spending authority and the amount that each is allowed to spend. In addition, it is beneficial to allow those with spending authority to have an input in the establishment of funds.

As for budget, a contractor may choose to maintain a bulk contingency account from which funds are withdrawn on an as-needed basis. The disadvantage is that all available funds may be withdrawn to support problem accounts early in the project; these accounts then show no variance in final accounting, while later accounts, lacking any backup, will show all the variance. It is better if the contingency account is allocated by period across the project based on relative risk. This promotes closer management of contingency. Figure 12 provides an innovative format for management of contingency when this is done. Note that for each reporting period, the overruns (+) or underruns (-) are itemized along with the allocated contingency for that period. When these are netted out, the overall overrun/underrun situation for the period is calculated and shown.

REPORT NO. ______ REPORT DATE ______		**Contingency Account Variance Register**		PROJECT ______ AFE NO. ______ JOB NO. ______
Report No.	Report Date	Description (All Costs Shown in 1,000's)	Cost	(±) Period Forecast Change
1	7/31/87	NET FORECAST CHANGE	......	..... + 9.8
		A) Target Cost Subcontracts: Onsites		
		1. Additional Scaffolding Costs	+ 31.4	
		1. Electrical Labor Escalation	+ 18.4	
		B) Target Materials: Onsites		
		1. Complete Tower Account	− 0.4	
		2. Piping, Requalify Welders	+ 4.5	
		3. Miscellaneous	+ 0.9	
		C) Planned Contingency Reduction	− 45.0	
2	8/31/87	NET FORECAST CHANGE	......	.... + 10.0
		A) Increased Cost Contractor Strike	+ 25.0	
		B) Provide Power to Control Room	+ 1.0	
		C) Planned Contingency Reduction	− 16.0	
3	9/30/87	NET FORECAST CHANGE	......	... − 42.2
		A) Capitalized Strike Cost for Nov.	+ 15.0	
		B) Drawing Escalation	+ 2.0	
		C) Miscellaneous Offsite Electrical	+ 0.8	
		D) Planned Contingency Reduction	− 60.0	

Figure 12. Contingency Account Variance Register

As for schedule, the contingency time is best distributed to provide flexibility preceding each key milestone in the project, particularly if those milestones have bonuses or penalties associated with their achievement. Management of schedule contingency is handled through comparison of critical path total float to contingency. Schedule contingency is a critical path activity.

As the project progresses and funds deplete, forecasts must be updated. A Contingency Status Graph can be drawn to depict planned and actual spending of contingency funds. When comparing the differences, consideration should be given to any project changes that have shifted the rate of contingency spending. The changed rates could either place a greater amount of risk in the early stages (producing an implied contingency deficit) or in a later phase, which would indicate a surplus. In either case it is management's responsibility to be aware of these potential changes and to make allowances for them. Managing contingency funds is a vital phase in a project's quest for cost control. As the impact of construction risks increases, so must the amount of control over contingency.

More on the subject is contained in a forthcoming CII publication, Construction Project Risk and Contingency.

7. SUMMARY

The potential for the success of a construction project is largely dependent upon the quality of the project controls system and staff assigned be cause that function is really the eyes and ears of management. Lacking this function or operating with a substandard system is equivalent to operating in the blind.

Project controls is concerned with cost, schedule, and materials control. These areas are extremely interrelated, and therefore the system must be designed to assure full accountability for their interrelationships. As is so often stated, there must be integrated project control.

Cost control is not cost accounting. The Cost Breakdown Structure provides the basic structure for cost control and establishes the Control Budget; its structure differs significantly from the structure for cost accounting. It is designed to catalog budgeted and actual expenditures for purposes of identifying cost problems, establishing cost trends during the course of the project, and to provide valuable cost data for the planning of future projects. Since the major cost variable on a construction project is labor productivity, a major component of the cost control subsystem is the tracking of work-hours in parallel with quantity tracking.

Schedule control requires the establishment of a Control Schedule at the outset of construction. This is the reference document for schedule planning and is modified only as a result of owner-approved changes. Working Schedules reflect the realities of progress to date and the plan for the short term. In all cases, the Working Schedules should be planned to keep the project as close to the Control Schedule as possible. The design of schedules should be such that they are realistic and a positive planning tool. Control Schedules which are too detailed soon lose their usefulness because they invariably contain arbitrary or false logic and field personnel no longer have confidence in them. A sure sign of schedule planning failure occurs when project control engineers can be found spending all their time updating schedules while the field personnel are planning their work as best they know how and simply reporting the results.

Materials control is one of the included functions of a Materials Management Program. Since materials deliveries directly affect the ability to schedule work, materials tracking should be a subsystem within the project controls system and tied to the scheduling system. The source of materials tracking information will come from procurement and expediting personnel, and positive coordination and cooperation with those personnel must be established and maintained throughout the project's life.

The Project Controls Section must be staffed by personnel knowledgeable about field operations. It should not be treated as an accounting or data processing activity, and should report directly to the field project manager. It should not share a computer system with another function if that sharing in any way denies the availability of the computer or printers to project controls. The project control engineers must be able to access databases and prepare reports for management at all times and on short notice.

Finally, the system must be designed to meet specific contractual requirements plus the traditional needs of the contracting parties.

APPENDIX

ACRONYMS USED

ACWP	Actual Cost of Work Performed
ADM	Arrow Diagram Method (of CPM Scheduling)
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CBS	Cost Breakdown Structure
CM	Construction Manager or Construction Management
CPI	Cost Performance Index
CPM	Critical Path Method (of Scheduling)
C/SCSC	Cost/Schedule Control System Criteria
CV	Cost Variance
CWH	Credit Work-Hours
DOD	Department of Defense
DOE	Department of Energy
EA	Each
EAC	Estimate at Completion
EPC	Engineering, Procurement, and Construction
EWH	Earned Work-Hours
FERC	Federal Energy Regulatory Commission
GC	General Contractor
LF	Linear Feet
MBE	Minority Business Enterprise
MMS	Materials Management System
PDM	Precedence Diagram Method (of CPM Scheduling)
PI	Productivity Index
QAB	Quantity Adjusted Budget
SPI	Schedule Performance Index
SV	Schedule Variance
U/M	Unit of Measure
WBE	Woman Business Enterprise
WBS	Work Breakdown Structure
WH	Work-Hour

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