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Project Control for Construction

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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.

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 sub-contracting 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 work-hour 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.

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.

DESCRIPTION

LEVEL

Total Project

Project

0

Area

Process
Limit

Off-sites

Interconnecting
Facilities

1

Category

Piping

Piping

Piping

2

Sub-Category

Hydrocarbon

Instrument
Air

Steam

3

Group

Line No.

Line No.

Line No.

4

Sub-Group
(Task)

ISO

ISO

ISO

5

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.