

THE CRITICAL PATH METHOD

by Sam Starobin

This powerful planning tool enables you to keep complex projects on schedule and to allocate resources wisely

As you grow from residential construction into larger and more complex projects such as small commercial buildings, you need more sophisticated planning tools. On your old familiar turf, you could probably anticipate most developments and handle them with seat-of-the-pants planning. But success in commercial work demands good project planning. Good planning lets you be a manager, not a fire-fighter.

Management Begins At Home

What do we mean by project planning? It is a process that starts with your construction contract and proceeds with a series of analytic steps to define just how you will deliver the product within the time and budget specified in the contract. You can tailor the planning process to your needs, increasing the complexity as the size of your projects increase. However, at the heart of every planning process is the project schedule.

Project scheduling has been around a long time. The Gantt chart, or bar chart as it is more commonly known, has been around since World War I in various forms. In the October issue of *New England Builder*, Sal Alfano describes a simple scheduling procedure. While these scheduling techniques are adequate for small jobs with simple relationships between construction activities, they cannot handle the more complex scheduling task you will encounter in commercial work. Here, you will have to deal with demands such as restraints on building activities and lags between activities.

To accurately schedule these more demanding jobs, you will want to use a variation of critical-path-method (CPM) scheduling. CPM scheduling methods also provide a mechanism for planning the efficient use of your construction resources. For example, you can't have one superintendent or one backhoe at two jobs at the same time.

There are many computer software programs that incorporate CPM scheduling. However, it is best to understand and master the simple manual methods of CPM before you tackle it on a computer.

CPM has its origins in "Critical Path Planning and Scheduling" (CPPS) developed in the 1950s by the DuPont company in collaboration with the

Univac Division of Remington Corporation to better manage refinery renovation project. During the same time period, the U.S. Navy in collaboration with the Lockheed Company developed a planning technique called "Project Evaluation and Review Technique" (PERT) for use on the Polaris submarine project.

CPPS and PERT both contributed to the planning system now known as the critical path method. In essence, this scheduling method requires the creation of a network showing the time relationship of construction activities. Some activities must precede others. For instance, in constructing a floor slab, excavation must precede placing forms and rebar which must precede placing concrete. Other activities can be done in parallel. Electrical work and mechanical work can generally be done as parallel activities. After creating the network of activities, several parallel paths of activities are usually developed. The path of activities that requires the longest time to perform is the *critical path*. Any delay in an activity on this path will delay the completion of the project. Other paths have some time leeway. This leeway is called float or slack.

CPM Variations

Two variations of CPM were developed for specific application to the construction industry, the arrow-diagram method (ADM) and the precedence-diagram method (PDM). The arrow network was the early favorite and became the industry standard. However, the precedence system provides a more straightforward system of diagramming activities and avoids some of the complexities of ADM. The precedence system has made a comeback and is used extensively in computer programs. Many computer systems refer to the precedence system as PERT. This is not accurate but provides a convenient terminology. It is well to be acquainted with the notation of both systems since you will be running into both types.

Both types of notation are based on networks consisting of arrows and nodes, a node being a box or a circle. In ADM an activity is depicted by an arrow which starts and terminates at a node. Each node represents the beginning or end of an activity. The activity is labeled by the beginning (i) node and the ending (j) node. In PDM, each node represents an activity and the arrows show the relationships between

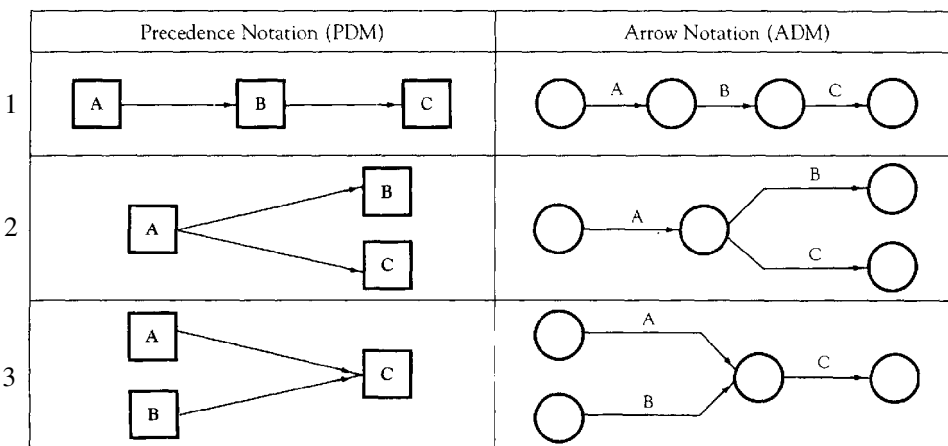
activities. In each system, nodes are numbered from left to right as they occur (simultaneous nodes are numbered arbitrarily). Figure 1 shows several simple construction activity relationships which I will discuss further.

A basic function of CPM is to identify restraints on activities—that is, the activities or events that must take place before a specific activity can take place.

In example 1 of Figure 1, activity A is a restraint on activity B which, in turn, is a restraint on activity C. Using the example of a foundation, excavation (activity A) must precede placing forms (activity B) which must precede placing concrete (activity C).

In example 2, activity A must be completed before you can start activity B and activity C which then proceed in parallel. In a simple example you must erect the walls (activity A) before you can run the electrical lines (activity B) and plumbing lines (activity C) in the walls.

In example 3, both activities A and B must be complete before you can start activity C. In a foundation, you must complete placing forms (activity A) and rebar (activity B) before you can place concrete (activity C).



Precedence and Arrow Notation

Figure 1

Figure 2 shows the construction plan for a concrete bridge footing using both PDM and ADM notation. Note the dashed arrows used in the arrow diagram. These are dummy activities—that is, they are needed to show relationships between activities but are not themselves activities. The dummy activity 20-30 shows that procuring piles as well as activity 10-30 (excavate) are restraints on activity 30-40 (drive piles). Similarly dummy activity 40-50 shows that activity 30-40 (drive piles) as well as activity 10-50 (build forms) are restraints on activity 50-60 (place forms). Note that these relationships are shown in the precedence diagram without the use of dummy activities. This is one of the major advantages of the precedence method.

Up until now, we have shown how CPM establishes the job logic, your concept for performing the work. To make this network of activities a true schedule, we must insert the time factor. A time duration must be assigned to each activity. But what duration? The time to accomplish a specific construction activity is generally not fixed but can be varied to some extent by assigning more or less resources, working overtime, etc.

The answer is to assign a duration based on your normal working pattern in regard to size of crews, working hours, etc. But keep in mind that durations can be adjusted to meet the needs of the contract or to make better use of your construction resources.

Insert the activity durations into your network and then add up the times required to complete each path. Figure 3 shows how this is done for our bridge footing project using ADM- and PDM-diagram notation. In ADM the duration of the activity is noted along the arrow and the cumulative time is shown at the node. The starting date for an activity goes at the start node and finish date at the end node. In PDM, the duration is shown at the bottom-center of the node, the starting date at the upper left-hand corner of the node and the finish date at the upper right-hand corner of the node. Remember that an activity cannot start until the latest finish date of preceding activities.

We see that the longest or critical path for this project comes to 36 days and runs through the following sequence of activities: procure piles, drive piles, place forms, place reinforcing steel, pour concrete. If any of these activities is delayed, the entire project will be delayed. Therefore this path has no float or slack. The other paths take less time and therefore do have float or slack. We now have to calculate the float or slack for each activity.

We have calculated the cumulative times at each node by adding the activity durations from start to finish of the project. We have performed a forward pass and established the early start (ES) and early finish (EF) for each activity. We now want to establish the latest time we can start and finish each activity. We do this by starting at the end activity and calculate the late finish (LF) and late start (LS) dates for each previous activity in turn by subtracting activity durations. Activities on the critical path will have the same early and late dates as stated above. Activities on other paths will have different early and late dates. Subtracting the early-start date for an activity from its late start gives you the float or slack for that activity. That is the length of time you can delay the start of the activity before you risk delaying the entire project.

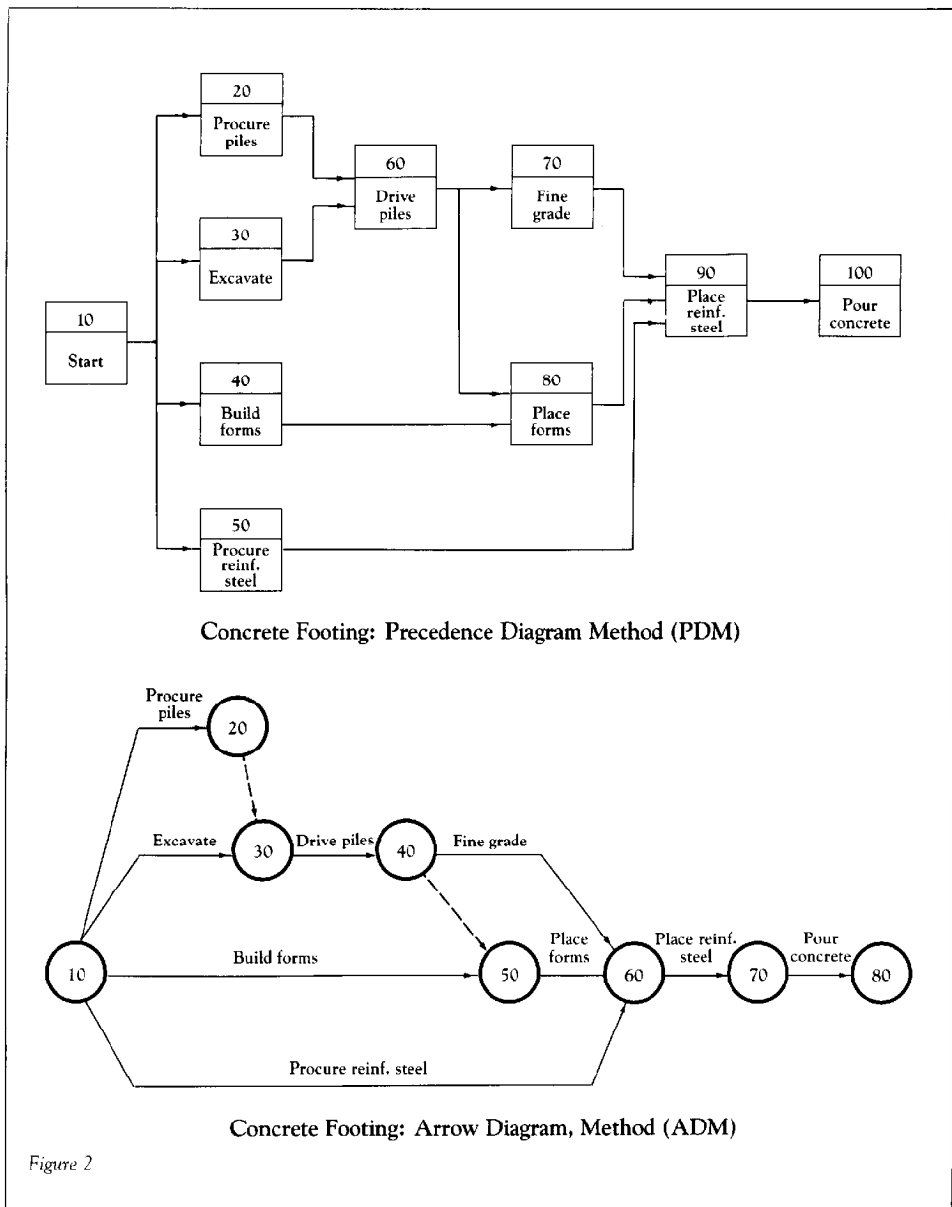


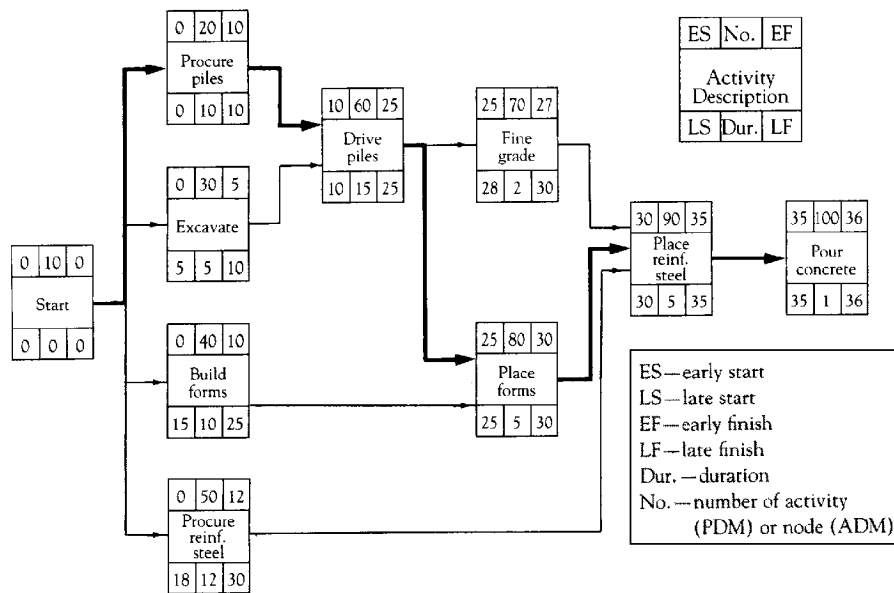
Figure 2

Figure 3 shows our bridge footing project with both early and late start and finish dates included. In PDM, the late start appears in the lower left corner of the node and the late finish appears in the lower right-hand corner of the node. In ADM, the late start or finish appears below the slash at the node. Interpreting the networks, we see that at the start of the project, we must start procurement of piles immediately since this activity is on the critical path. We can delay the start of excavation for as long as five days, delay the start of building forms for as long as 15 days and delay the start of procurement of reinforcing steel for as long as 18 days. Since we constantly face the problem of juggling time and resources in construction, CPM provides a logical basis for those daily decisions. Now we know what must be done today and what can be put off and for how long.

Working off a network diagram can be confusing so the data on the network is frequently printed in a table such as Figure 4. The work days are converted into calendar days. This gives the basic schedule information, the activity identifications, the early start and finish dates, the late start and finish dates, and the float or slack for each activity.

This article describes the basic functions of CPM: establishing the job logic and showing which activities are critical and must be kept on schedule and which have float or slack time. CPM has further uses as well. We can insert lag relationships between activities since not all activities start neatly after the completion of others. And we can use CPM to plan the most efficient use of money, labor, and equipment. But first become comfortable with its simple scheduling capabilities shown here. Then go on to its more sophisticated uses. It is a powerful tool, particularly when teamed with the computer, and one you cannot afford to ignore. ■

Sam Starobin is an engineering and construction manager with Stone & Webster Engineering Corp., in Boston Mass. He is currently conducting a series of seminars on construction management at Lowell University in Lowell, Mass. Call Lorraine Lupien at 617/454-4664 for details.



Concrete Footing: Precedence Diagram Method (PDM)

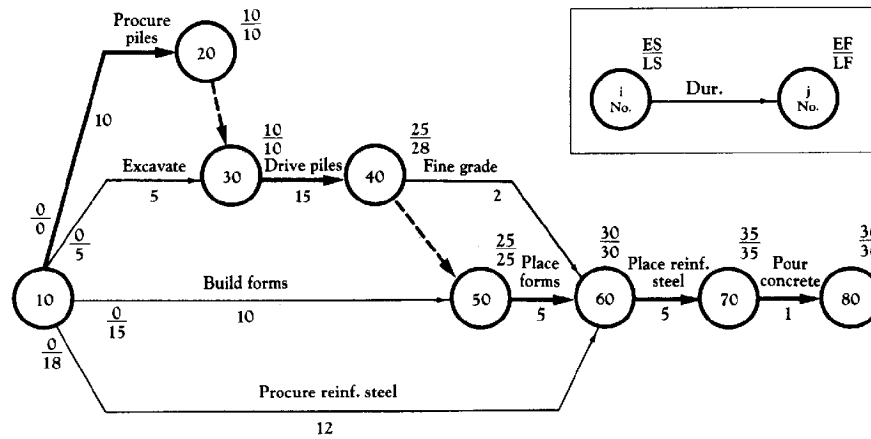


Figure 3

Concrete Footing: Arrow Diagram Method (ADM)

CONCRETE FOOTING SCHEDULE

Activity	Designation Label		Duration Days	ES	EF	LS	LF	Float	Critical Activity
	ADM	PDM							
Procure Piles	10-20	20	10	6/14	6/25	6/14	6/25	0	X
Excavate	10-30	30	5	6/14	6/18	6/18	6/25	5	
Build Forms	10-50	40	10	6/14	6/25	7/2	7/19	15	
Procure Rebar	10-60	50	12	6/14	6/29	7/8	7/26	18	
Drive Piles	30-40	60	15	6/25	7/19	6/25	7/19	0	X
Fine Grade	40-60	70	2	7/19	7/21	7/22	7/26	3	
Place Forms	50-60	80	5	7/19	7/26	7/19	7/26	0	X
Place Rebar	60-70	90	5	7/26	8/2	7/26	8/2	0	X
Pour Concrete	70-80	100	1	8/2	8/3	8/2	8/3	0	X