

Intro to Critical Path Scheduling

by David Carns

With CPM, you'll know when each task must be started and finished to complete the job on schedule

Simple construction projects rarely have formalized schedules. But as projects increase in size and complexity, involving more labor, materials, and equipment, you may need a scheduling technique that will give both you and the owner a better picture of a job's progress.

A good scheduling system gives you several benefits. One is that you can get a good financial picture of the project. Both your costs and the owner's are closely related to a project's duration. The sooner a project is completed, the sooner the owner can use the building, and the sooner you, as builder, can direct your resources to other jobs.

In addition, a good scheduling system:

- establishes critical "must-do" dates and other milestones, such as start and finish of the job, and the latest dates to obtain permits, order materials, and call subs;
- helps subs and suppliers see how they fit into the overall picture;
- helps avoid resource conflicts, such as scheduling two jobs for the same time period that each require three carpenters when you have only four carpenters available;
- forecasts cost and payment information to help with cash flow on a job; and
- serves as an excellent sales tool, convincing both owners and financiers of a project's value. If you've taken the time and made the effort to analyze a job's progress before it even starts, you are probably one step ahead of the competition.

Finally, the more sophisticated scheduling systems can show how the various activities in a job depend on each other, as well as their expected durations. This lets you see at a glance which items you must start and complete at any given time in order to finish the job on schedule.

The Importance of Networking

There are several common

scheduling methods used by contractors. One of the most basic, the bar chart (see Figure 1), shows the start and finish time of each activity, with each activity designated by a horizontal bar running above a time line. The bar chart is a good basic tool, but it does not show which activities depend on others. This can lead to trouble, since it's easy to lose track of which steps in the process must be

completed before others can begin.

A different type of scheduling system shows the interrelation between different stages of construction. Rather than having each activity shown with a separate bar, the activities are linked in a *network* representing their relationships and interdependencies.

For small and medium-sized builders, the most relevant network technique is called the Critical Path Method, or CPM. This method is often used in large commercial projects. But small builders working on complete houses or moderate to large remodels can also benefit from the extra organization — and therefore flexibility — that CPM provides.

Linking the essentials. The main goal of CPM scheduling is to clearly identify and link the stages of construction that form the project's "critical path" — the sequence of interrelated activities that determine the project's minimum duration. Any delay in these activities will mean a delay in the project completion date.

A CPM flow chart (see Figure 2) links these critical activities along a central critical path that forms the backbone of the construction process. Activities that are not critical (in the sense that there is some flexibility regarding their completion time) are represented on work paths that branch off of the critical path.

CPM can look intimidating at first. But once you know how to make and read a flow chart and have worked through a job or two with the system, you should be able to use it easily. I'll walk through a sample pro-

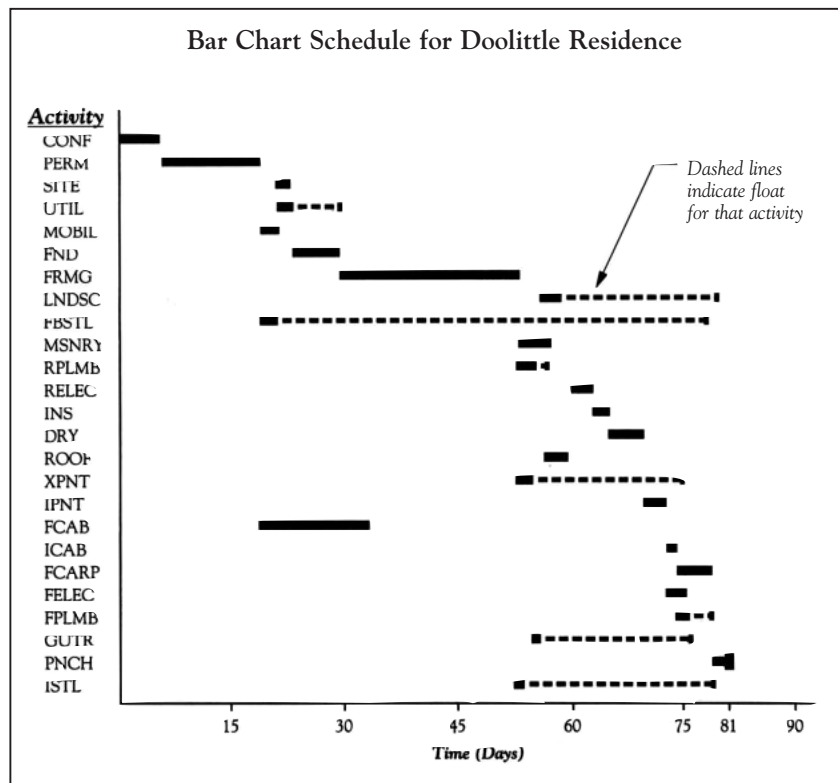


Figure 1. The bar chart is a common scheduling tool useful for showing the start and finish time of each activity. It is limited in that it doesn't show which tasks must be completed before others can begin.

CPM Schedule — Doolittle Residence

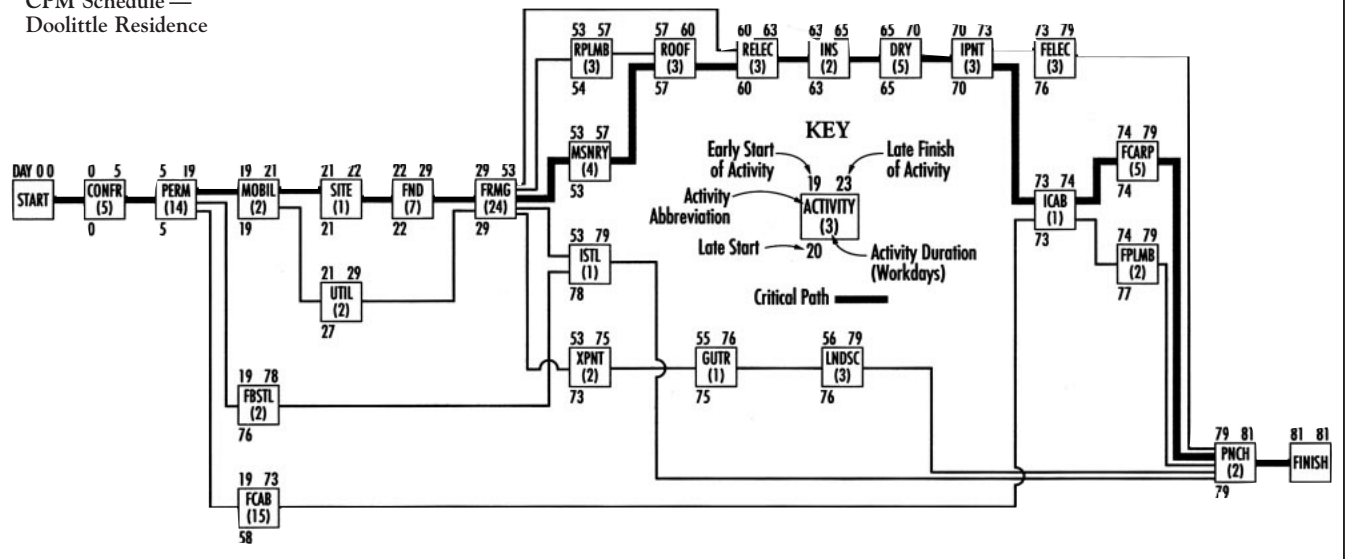


Figure 2. A CPM flow chart links activities along a central critical path that forms the backbone of the construction process. Activities that are not critical (in the sense that there is flexibility regarding their completion time) are represented on work paths that branch off the critical path.

ject here to show the steps involved and how to construct and read a CPM schedule.

Creating a Schedule

Let's say you need a schedule for a custom home you are planning to build for the Doolittle family. Here's how to begin:

Step 1: Define activities and their durations. This is something you probably already do for every job,

at least in your head. Break the project into individual work activities, and give each stage a three-to-five-letter abbreviation, as shown in Table 1. Consider work crews available, equipment needed, assemblies to be fabricated off-site, and any sub-contracts required. The level of detail you use for these categories depends on the project's size and complexity as well as the intended use of the schedule. You must also

establish a time duration for each activity. These are usually given in work days.

The order of the list doesn't matter at this point, though it's usually easiest to list them in the rough order in which they will occur. Table 1 shows the list of activities and their dura-

tions for the Doolittle's custom home, beginning with the conference with the Doolittles and their architect and engineer.

Step 2: Establish relationships.

Next, establish the relationships between the activities you listed in Step 1. To do this, make a list indi-

Table 1. Activities and Durations

Activity	Symbol	Duration(days)
Confer with A/E owner	CONFR	5
Obtain permits	PERM	14
Sitework and excavation	SITE	1
Utility work	UTIL	2
Mobilize workforce and equipment	MOBIL	2
Foundation work	FND	7
Framing	FRMG	24
Install steel railing	ISTL	1
Landscaping	LNDSC	3
Fabricate steel railing off site	FBSTL	2
Masonry chimney	MSNRY	4
Rough plumbing	RPLM	3
Rough electrical	RELEC	3
Insulation	INS	2
Drywall	DRY	5
Roof	ROOF	3
Exterior paint	XPNT	2
Interior paint	IPNT	3
Fabricate cabinets off-site (includes order time)	FCAB	15
Install cabinets	ICAB	1
Finish carpentry	FCARP	5
Finish electrical	FELEC	3
Finish plumbing	FPLMB	2
Install gutters	GUTR	1
Punch list	PNCH	2

Table 2. Activities and Prerequisites

Activity	Symbol	Prerequisite
Confer with owner /AE	CONFR	Start of job
Obtain permits	PERM	CONFR
Sitework and excavation	SITE	MOBIL
Utility work	UTIL	MOBIL
Mobilize workforce and equipment	MOBIL	PERM
Foundation work	FND	SITE
Framing	FRMG	FND, UTIL
Install steel railing	ISTL	FRMG, FBSTL
Landscaping	LNDSC	GUTR
Fabricate steel railing off site	FBSTL	PERM
Masonry chimney	MSNRY	FRMG
Rough plumbing	RPLMB	FRMG
Rough electrical	RELEC	FRMG, ROOF
Insulation	INS	RELEC
Drywall	DRY	INS
Roof	ROOF	RPLM, MSNRY
Exterior paint	XPNT	FRMG
Interior paint	IPNT	DRY
Fabricate cabinets	FCAB	PERM
Install cabinets	ICAB	IPNT, FCAB
Finish carpentry	FCARP	ICAB
Finish electrical	FELEC	IPNT
Finish plumbing	FPLMB	ICAB
Install gutters	GUTR	XPNT
Punch list	PNCH	FCARP, FELEC FPLMB, ISTL LNDSC, UTIL
Finish job		PNCH

CPM on Computer

You can comfortably create a CPM schedule by hand for very small construction projects. But when it comes to projects the size of the Doolittle house or larger, you'll want to do it on computer.

The Power of Software

No computer program can divide your project into its separate activities or assign durations to, and recognize relationships between, the activities. These are decisions that come from your own experience and judgment about the project. CPM software can, however, do the following:

- Perform all calculations, including the forward and backward passes, to determine the early and late starts, float times, and so on, almost instantly.
- Account for the real calendar in translating "schedule days" into actual work days on your calendar. Most CPM software considers work and non-work days (weekends, national holidays, etc.) when calculating the schedule. So instead of "Day 62," for example, you would see "Tuesday, Aug 12."
- Allow easy updating. What if durations change? What if the precedence relationships change? What if activities are added (or deleted) through change orders? All of this can be easily handled with most CPM software, where it could be a nightmare to revise by hand.
- Print both bar charts and CPM networks.

In short, computer software makes CPM scheduling much more usable — a real tool, and maybe even a pleasure, rather than a chore.

Features to Look For

Choose software that is designed with you in mind, not software designed for huge commercial projects or industrial processes. Define your needs and compare them to what is available. Consider the following:

- **Ease of use.** Will this software become useful without being overly complex?
- **Hardware requirements.** Does it require greater hardware than you have (such as more memory or a hard drive), and if not, are you willing to spend for the difference?
- **Graphics capability.** Will it print both bar charts and networks? Networks are most useful for visualizing a project, but bar charts can be useful for sizing up progress at a quick glance. With some programs, these graphic capabilities are sold separately.
- **Output.** Can the network be printed on your printer? Some may require expensive "plotters," large printers that can print on wide paper.
- **Flexibility.** Other than the basic schedule, what other reports can you derive and print from the program? Are these useful to your business?
- **Support.** Is the manual easy to use? Is technical support readily available?

You might also check whether a program has some of the more advanced scheduling features, if you think they'd be useful. These include:

- **A resources feature.** This allows you to add labor, equipment, and material costs to the activities. It can be useful as an estimating tool and as a means of forecasting and tracking cash flow throughout a project.
- **A resource leveling feature.** This helps level the personnel and equipment requirements on the job, so that you don't have peaks and valleys of demand for labor or equipment.
- **Integration** with other related software packages, such as estimating programs.

Software Suggestions

Much of the CPM scheduling software on the market is geared to large-scale commercial and industrial projects. Programs that may prove the most valuable to the smaller volume contractor include:

- **Advanced Pro-Path 6** (SoftCorp Inc., 2340 State Rd. 580, Suite 244, Clearwater, FL 34628; 813/799-3984; \$199 for the program, \$59 for network graphics). For IBM-compatibles. This is an affordable, easy-to-use program with calendar, resource, and reporting capabilities.
- **Microsoft Project Version 4.0** (Microsoft Corporation, 16011 NE 36th Way, Redmond, WA 98073-9717; 800/227-4679; \$495). This is the program I've had the most experience with. It's well-documented with an easy-to-follow manual and a self-paced tutorial and good support from Microsoft. The program is complete to the point that it should be able to handle the needs of most mid-sized commercial contractors. But it's simple enough to prove useful on smaller jobs as well.
- **Claris' MacProject II** (Claris Corp., 5201 Patrick Henry Dr., Santa Clara, CA 95052; 408/727-8227; \$499). For Macintosh users, construction computer consultant Eric Freed of Carefree, Ariz., recommends MacProject II, which can generate flow charts and do backward and forward passes and other computations.

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cating which activities must immediately precede each activity in question — their immediate *prerequisites* (see Table 2). For example, you don't want to obtain your permits until you've finalized things with the owner, so the conference activity (CONFR) becomes a prerequisite for the permit stage (PERM). And you can't begin framing (FRMG) until you have both the foundation and utilities in, so foundation (FND) and utilities (UTIL) are listed as prerequisites for framing. Don't list everything that comes before a step, only its immediate prerequisites.

Establishing these relationships requires visualizing how the project will be built and the interaction between subs, work crews, and suppliers. Take some time with it. It requires a lot of thought and forms the basis of the schedule.

Step 3: Build the network. The next step is to create a flow chart or network that schematically shows each activity and how it relates to the other construction activities, based on the prerequisite relationships established in Step 2. The different "paths" for the network are shown by the lines connecting the boxes. Each box represents a construction activity, as indicated by its abbreviated symbol.

The boxes go in the order their activities occur, from left to right. Each should have inside it the abbreviated name of the activity and, in parentheses, the number of days the activity will take to complete.

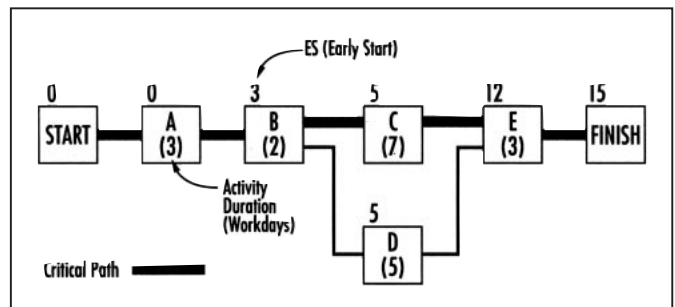
As you work from left to right,

Analyzing the Network

With the network properly constructed, you have a good flow chart showing how the activities follow one another, their interdependencies, and the duration of each. From that information you can glean several other crucial facts about each stage so that you'll have not just a flow chart, but a true critical path schedule.

Establishing an early start. Using what is called a "forward pass," you can work through the network to establish the early start (ES) time for each activity. The early start is simply that — the earliest that an activity can be started, based on the durations and interrelationships of the preceding activities. The forward pass is simply a matter of working your way left to right through the network to find the *longest path through the network*. This will identify not only the early start time of each activity, but the network's critical path — the path in which any delay will cause delay in project completion. This is also the soonest the project can be expected to be completed, assuming your estimates of the duration of each task are correct.

Start with the first task, which in this example is the architect and owner conference (CONFR). We assign it an ES of 0 (zero). The ES of any other activity is found by choosing the *longest possible path* in days to that activity. This is done by moving left to right through the network, adding the ES of each activity to its duration to find the ES of the follow-



you'll find that paths will branch off at certain points, where one activity's completion allows the simultaneous start of several others — the completion of framing, for instance, makes possible the start of several other activities, each of them beginning a new path. Some of these paths will rejoin later.

We'll analyze the network later to identify information such as early and late start times and "float times" for each activity. For now, the main thing is to get the boxes lined up in their proper order and relationships. It may take two or three tries at a network before you get it flowing neatly so it's easy to read, and so there aren't more paths than necessary. Always move left to right.

ing activity.

For example, consider the simple network below:

Since there is only one path to activity B, the early start of B is found by adding the ES of A plus its duration ($0 + 3 = 3$). The early start of C is then found by adding the early start of B (3) to B's duration (2), yielding 5 days ($3 + 2 = 5$). D's early start is found in a similar manner.

Activity E is tricky, because it has two paths leading to it, one from C and one from D. To find its early start date, you take the longest path: Hence E's earliest start is found through C, which has an ES of 5 and lasts 7 days ($5 + 7 = 12$ days).

In this example the project will finish in 15 days. All the activities except activity D are on the critical

path, which is the longest path through the network. The activities on the critical path are known as "critical activities," and their delay will delay the project. Activity D is non-critical and hence has some "float" or "slack" time, which will be discussed later.

List the ES for each activity above the box's upper left hand corner.

Completing a forward pass for the Doolittle residence shows that the house can be completed 81 work days after it is begun, since the last activity, punch list (PNCH), can be started after 79 days and takes two days to complete.

The Backward Pass

A "backward pass" through the network yields the late finish (LF) of each activity. That is the latest an activity may be completed without delaying the overall completion date of the project.

In the backward pass, we start at the end of the job, by assigning a late finish date to the very last activity in the network equal to its ES — in the Doolittle's case, 81 days for the punch list. (By definition, this is the last day the job can be completed without delaying it beyond its 81-day schedule.)

Next we follow all the paths backward, one activity at a time, assigning late finish dates. Do this by taking the late finish of the following activity (the activity to the right) and *subtracting* that activity's duration. Then write the result above the upper right hand corner of the box for the activity you're working on. If there is more than one path back to an activity, perform this same subtraction for each of the paths, then choose the lower value as the late finish.

For example, in the Doolittle job, Install Cabinets (ICAB) is followed by boxes with durations 5 days (FCARP) and 2 days (FPLMB), both of which have late finish days of 79. Subtracting these durations from their common finish day of 79, we get figures of 77 and 74; we use 74 as the late finish day for ICAB, for that is the last day we can finish that activity without delaying the project's completion. If we went with 77, we'd delay everything an extra three days.

Late Start

From the late finish, we can easily derive one of the most important pieces of information about each activity, its late start. This is the latest an activity may be started without delaying the project. To get it, we simply subtract its duration from its late finish day. For instance, for installing cabinetry — ICAB — the late start is 74 (its late finish day) minus its duration of one day, or 73. That's the last day we can start that job without delaying the project.

Write the late start beneath the

lower left hand corner of the activity box.

Late start dates are quite useful, since they let you know exactly when each activity *must* begin. They also provide information for subcontractors and suppliers as to how they fit into the overall schedule.

Float or Slack Times

The float or slack time of an activity is the length of time its actual start may be delayed beyond its early start without delaying the project — in other words, it's the slack between its early and late start times. You get it by subtracting an activity's duration plus early start from its late finish: $LF - (ES + \text{Duration})$.

By definition, all activities on the critical path have zero float time, because their cumulative early starts and durations provide the length of the critical path itself.

However, many activities outside the critical path have float times, and it's worth knowing those, for they represent the areas where you have some leeway in scheduling. To know that you have 39 days of slack concerning the Doolittle's FCAB (fabricate cabinets), for instance, means that if you want to, you can delay the order in case some design change is made or the Doolittles aren't quite sure yet which cabinets they want.

Using the CPM Network

Besides the obvious advantage of helping to visualize a project's progress on paper, a CPM network can provide answers to some very important questions.

For example, say the finish carpenter wants to know when he must be on the job and if he has flexibility as to how long he can take to complete his work. By looking at the schedule we see that the finish carpentry (FCARP) is scheduled to begin at the end of day 74 (or the beginning of day 75) and to take 5 days. This activity lies on the critical path, so any delay will delay the project. Break the bad news to the finish carpenter.

Another example: You realize at the end of the 62nd workday that the painters haven't begun painting the house exterior, and you seem to remember they were going to start around day 50. Is this a problem?

A look at the schedule shows it is not. The early start day for XPNT is day 53, but because the only thing waiting on it is the punch list, XPNT has a float of 20 days, with a late start day of 73. The 9-day delay so far is not a problem. The painters still have 11 float or "free" days left to begin their work before the completion of the project will be delayed. ■

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