Critical Path Method (CPM) Tutor for Construction Planning and Scheduling

E. WILLIAM EAST

Mc Graw Hill Education

Critical Path Method Tutor for Construction Planning and Scheduling

E. William East

McGraw Hill Education

New York Chicago San Francisco
Athens London Madrid
Mexico City Milan New Delhi
Singapore Sydney Toronto

Cataloging-in-Publication Data is on file with the Library of Congress.

McGraw-Hill Education books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. To contact a representative please visit the Contact Us page at www.mhprofessional.com.

Critical Path Method Tutor for Construction Planning and Scheduling

1 2 3 4 5 6 7 8 9 0 QVS/QVS 19 18 17 16 15

ISBN 978-0-07-184923-4
MHID 0-07-184923-8

The pages within this book were printed on acid-free paper.

Sponsoring Editor
Robert Argentieri

Editorial Supervisor
Donna M. Martone

Acquisitions Coordinator
Amy Stonebraker

Project Manager
Ruchika Abrol, MPS Limited

Copy Editor
Surendra Shivam, MPS Limited

Proofreader
Garima Sharma, MPS Limited

Indexer
Diana Witt

Production Supervisor
Pamela A. Pelton

Composition
MPS Limited

Art Director, Cover
Jeff Weeks

Critical Path Method Tutor for Construction Planning and Scheduling

About the Author

E. William (Bill) East is an internationally known construction management researcher whose career spans the areas of planning and scheduling, quality management, and building information modeling. While with the U.S. Army Corps of Engineers, East created the Corps' Standard Data Exchange Format (SDEF). He also developed parametric planning and automated schedule analysis tools, and provided related consulting services on Corps' and Army projects. East's Design Review and Checking System (DrChecks^{SM}) streamlined design quality management for public project stakeholders at the federal, state, and local levels. Most recently, East invented the Construction-Operations Building information exchange (COBie)—an international standard that squeezes profits from an otherwise wasteful construction handover process. East has degrees in Civil Engineering from Virginia Tech (B.S.) and the University of Illinois (M.S. and Ph.D.). East is a registered Professional Engineer in the state of Virginia and is a Fellow of American Society of Civil Engineers (ASCE).

For John Melin

Preface

When I started my career as a U.S. Army Corps of Engineers project engineer, I found that neither formal education nor available training prepared me for the day-to-day business of using Critical Path Method (CPM) schedules to evaluate progress payments, determine the impacts of contract modifications, or conduct claims analysis. After moving from the field to the Construction Engineering Research Laboratory, I had the opportunity to use and grow my experience through consulting and schedule analysis services for projects both large and small. One of these projects was the Standard Data Exchange Format (SDEF) for project scheduling. Contractors have been submitting their monthly progress schedules to the Corps of Engineers using SDEF for the last three decades.

When asked to join the faculty at the University of Illinois at Urbana-Champaign, I jumped at the chance to share my hands-on experience. I updated the project planning part of an introductory course in construction management to simply explain CPM and provide practical explanations of why and how specific scheduling practices were helpful. With the later advent of the Internet, notes from that class became the popular CPMTutor.com website. Over the years, practitioners, students, and educators visiting CPMTutor.com asked me to develop my materials into a book. You are looking at the result of those requests.

The effective and consistent use of the techniques introduced in this book will help the reader to:

- Reduce progress payment disputes and speed progress payment
- Plan resources for maximum productivity
- Predict owner-caused and weather delays
- Develop "get well" plans for projects that fall behind
- Correctly update progress, including out-of-sequence activities
- Meet contracts requiring CPM schedules
- Evaluate change and claim impacts; develop admissible documentation

While some may be more inclined toward planning than others, planning is an essential human activity that anyone can learn. I hope that the approach taken in this book, to explain both the "why" and the "how" of CPM scheduling, will be helpful in your quest to bring every project on time and under budget.

Thanks to Dave Quigley for helping me find a home for this book at McGraw-Hill Education and for his helpful manuscript reviews. Also thanks to Dana Finney, Kathryn East, and Ruchika Abrol for their help with copyediting. Finally, thanks to those of you who have contacted me through the CPMTutor .com asking how to get this book!

E. William East, Ph.D., P.E., F.ASCE
Prairie Sky Consulting
November 2014

A Note on Typography: *When referring to activities on a construction schedule, this book will always surround the name of the activity with quotation marks. For example the activity named "Task 1" is always shown in quotes as the activity named "Activity A" or "Backfill."*

Many terms in the Critical Path Method (CPM) have acronyms that are widely used in this book. In cases where these terms do not have acronyms these terms will remain capitalized, as if they were proper nouns. This is done to emphasize and reinforce the definitions of these specific terms and phrases.

Contents

CHAPTER 1

Why Scheduling?

The need to formally schedule projects often starts without a proper introduction. For example, a small contractor gets their first job with a new, large owner. That owner's contract requires a Critical Path Method (CPM) schedule. In other cases, a new engineer at a general contractor's office may be told to create a computer schedule without knowing how to go about doing it. Due to time constraints, students may only have the opportunity to learn the mechanics of scheduling. In each of these cases, the person creating and using the schedule can easily miss the reason for making a schedule in the first place.

This chapter explains what a construction schedule is and is not, and describes the benefits that can be achieved through the use of an effective construction schedule. Understanding these basics before applying the mechanics of scheduling will help the reader to understand the purpose, value, and limitations, of the techniques presented in this book.

What Is a Construction Schedule?

A construction schedule is a model of the steps required to complete a construction project. It is very unlikely that two construction schedules will be exactly the same because no two construction projects are exactly the same.

A construction schedule is not an exact model of a construction project. Like any other model, a schedule approximates some aspects of a construction project and completely omits others. If the scheduler understands the trade-offs made when creating the schedule, then the schedule can be a very useful tool indeed.

Effective project schedules include: (1) the sequence of activities needed to complete the work, (2) the duration of those activities, (3) the flow of crews through the project who perform those activities, and (4) the value generated by the completion of each activity toward the overall completion of the project.

Rather than simply using a schedule to meet a contractual requirement, effective scheduling helps the project team anticipate and resolve potential problems before they occur. The effective use of schedules also helps the team quickly evaluate and resolve problems that ultimately arise on large or complex construction projects. The paragraphs below discuss the specific questions that can be answered if the project team adopts and uses scheduling best practices.

Will the Project Finish on Time?

The most common reason that owners include schedules in construction contracts is that owners assume that the initial schedule and monthly updates will present an accurate account of work completed and a prediction of work remaining. Schedules developed for the sole purpose of meeting owners contract requirements are often created by off-site personnel. If sufficient effort is made to discover on-site conditions and subcontractor constraints, then these third-party schedules may result in good initial schedules. Initial schedules help to determine if a construction sequence will be able to complete the project with the allotted duration.

After the submission of the initial schedule, the schedule is required to be updated monthly to identify efforts toward completion. Schedule updates that take account of local site and job conditions can be good predictors of the ability of an ongoing construction project to complete the project within the remaining time.

Is the Project on Schedule?

If a contract requires a construction schedule, it is likely that the schedule will also be used as a basis for periodic progress payments. Often the use of a schedule in this case is simplified to be a "schedule of values" without regard to the sequence and physical progress of each individual activity. If, however, the schedule is used correctly, the value of in-progress and completed activities can help to identify differences between the project plan and actual performance. Correctly defined schedules track both the time and cost (or earnings) completion of each activity. This means that schedule activity updates must reflect those tasks that are actually taking place on the jobsite, not the initial "schedule of values." Correctly defined in-progress activities report two values each month: "Remaining Duration" and "Percent Complete."

Separating time from cost allows activities that have large up-front equipment costs to correctly accrue earnings. The day after delivery of a generator the "Install Generator" activity may have, for example, a Remaining Duration equal to the Original Duration and a Percent Complete of 75%.

Another way that the correct evaluation of in-progress activities can occur is to identify work that is falling behind schedule. Consider an activity, such as wall painting, that typically uses the same amount of resources each day. For such activities we could expect that if 75% of the value of the work has been earned, then the time required to complete the activity would be about 25% of its Original Duration. If, however, the owner paid for 75% of the activity's value, but it was estimated that the activity had 75% of its duration left to complete, then the activity is in trouble.

What Crews Should Be on Site Today?

On complex projects, one of the most difficult coordination efforts is ensuring that subcontracting crews arrive in a sequence that allows trades to follow one another. Where many trades are present, one trade out of sequence can result in rework. The coordination required is not a technology problem, nor a problem that requires new programs and management; it is simply a planning and communication problem. The communication can be made more clear through the use of schedules that model crews' flow through a project.

If schedules specifically identify subcontractor activities, then the timing for the arrival, scope of work, and departure of subcontractor crews can be clearly described to all stakeholders. Using the schedule as a communication vehicle can help decrease miscommunications. If there are delays or scheduling conflicts, then the impacts of these delays on following contractor and/or subcontractor activities may be clearly identified.

What Happens If?

If the initial schedule accurately reflects the way that the prime and subcontractors plan to do the work, and the schedule is updated as the project goes along, then the schedule can predict what may happen if changes are introduced to the plan. Schedule changes will directly add or remove specific activities and may also impact other activities and the overall completion of the schedule. Having a mutual understanding and agreement on pending change requests during the course of the project is usually preferable to legal depositions and court appearances years after a project has completed.

What Happens Now?

The Google search on "Why bad things happen to good projects" turns up over 375 million hits! Anyone who has ever been on a construction site can write that book. A schedule that accurately reflects the initial project plan and is updated to reflect changes during the project allows the team to quickly identify and mitigate problems that arise. Following that, the impacts of these problems can be quickly addressed in appropriate contract changes before the project reaches the "claims phase."

What Happened?

If accurate initial and updated schedules are not properly maintained, it will fall to the claims team to answer the question of "what happened?" The team will use those schedules or schedules of value that were available, along with daily reports, jobsite photos, invoices, submittals, and payroll records to reconstruct an accurate picture of the construction schedule. Of course, doing this after everyone has left the jobsite and may not even be available to be interviewed is not the mark of an effective scheduling effort. Projects scheduled using the techniques described in this book should be able to avoid the grueling and nonproductive effort needed to resolve issues during the claims phase.

What Is a Control Cycle?

Imagine how long it would take to get a new car if the manufacturer simply delivered all the parts to each house and the workers had to travel to each location and assemble the car. This is exactly what happens on a construction site. Construction projects create a temporary factory on the jobsite. While premanufacturing of duct-runs and pipe-spools is being used more often, assemblies are still connected at the jobsite.

In the factory, it is possible to directly measure the productivity, quality, and cost of each step of the manufacturing process. On the construction site, the project team relies on the quality control, quality assurance, standard and repetitive detailing, and personal experience to ensure that the job is done to the level of quality required by the construction contract. Over time, construction management tools have been developed to assist in these tasks. These tools are applied as part of "control cycles."

Control cycles allow managers to define objectives for a specific aspect of the project, measure the performance of the work as it proceeds, evaluate the work against the predefined objectives, and decide if adjustments are needed to resolve any difference between plan and actual. Effective project managers agree that there are four different aspects of projects that require such control cycles: time, cost, quality, and scope.

The typical controls for each topic, time, cost, quality, and scope are outlined in tables below. In each table, the first column, Component, lists those aspects of a project typically managed under that control regime. The second column, Element, identifies the specific area of study needed to address the topic. The third column, Concerns, identifies the choices available to managers when faced with decisions regarding these elements. The forth column, Technique, lists techniques or methods used by project managers to help them make such decisions.

Table 1.1 identifies the Components, Elements, and Concerns related to time control. This table is the one directly related to the contents of this book. The two components of time control that must be addressed are Sequence and Duration. Of all the

Component	Element	Concern	Technique
Sequence	Sequential Parallel	Trade interaction Work area access Physical constraints Common practice	Fenced bar charts CPM PERT Line-of-Balance
Duration	Productivity	Technology choice Equipment choice Crew size	Seat-of-pants Bar charts

TABLE 1.1 Time Control

time-control techniques, CPM is the most widely applicable. Other time-control techniques are discussed in this book to highlight the importance and value of CPM.

Table 1.2 identifies cost control techniques often grouped together in "engineering economics" studies required of undergraduate civil engineering students. Students in business schools will also recognize many of these techniques as essential

Component	Element	Concern	Technique
Material	Direct costs	Price	Inventory control Just-in-time delivery Storage
	Indirect costs	Waste Shortages Handling cost	Example "panels" Fabrication detailing Laydown simulations Barcode/RFID tracking
Labor	Direct costs	Productivity Wage rates	Crew selection Crew size Subcontracting Overtime use
	Indirect costs	Mobilization Overheads	On-site storage Job conditions Breakeven analysis Learning curve
Equipment	Direct costs	Efficiency Productivity Operating cost Maintenance cost	Rent/lease/own Storage/transportation Tire management Service contracts
	Indirect costs	Depreciation	Rent/lease/own

TABLE 1.2 Cost Control

Component	Element	Concern	Technique
Materials	Life-cycle costs Maintenance costs	Incorrect application High operating costs High disposal cost	Codes and standards Specifications Submittal compliance
Installation	Tear-out Rework	Incorrect installation Trade conflicts Crew productivities	Training Crew sequencing Quality control

Table 1.3 Quality Control

elements of managerial accounting. The complete coverage of cost control is outside the scope of this book; however, since "time is money," those aspects of cost control that can be illuminated by construction scheduling will be introduced in this book.

Quality concerns, shown in Table 1.3, are the third type of control system put in place on most construction projects. The quality control system ensures that the work meets the quality requirements identified in the plans and specifications. Far from being an abstract idea, quality in construction is defined by the construction contract itself. Given the wide variety of materials, products, equipment, and crews on a jobsite, the question for a contractor is how to achieve the specified quality at the least cost.

The impact of time-control techniques on quality control is primarily a matter of trade sequencing. If, for example, both sides of an interior partition are completed prior to installing electrical conduit and plumbing, part of that newly built wall will have to be torn out and subsequently repaired. The scheduler needs to be sure that work is accomplished with as little tear-out and rework as possible. To reduce tear-out and rework, activities will generally be scheduled using an "inside-out" sequence. In other words, the work to be covered up comes before the work that covers. A practical example in a mid-rise office building is that the heating, ventilating, and air-conditioning (HVAC) ductwork above the ceiling is installed before the ceiling grid is installed. Once the grid is installed, the diffusers and flexible connections to the diffusers can be installed. To install the ceiling grid and tiles before the HVAC system would result in significant tear-out and rework.