construction project scheduling and control

SECOND EDITION

SALEH MUBARAK

Construction Project Scheduling and Control

Construction Project Scheduling and Control Second Edition

Saleh Mubarak

WILEY
John Wiley & Sons, Inc.

This book is printed on acid-free paper. ♾

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

This book was previously published by: Pearson Education, Inc.

Library of Congress Cataloging-in-Publication Data:

Mubarak, Saleh A. (Saleh Altayeb)
Construction project scheduling and control/Saleh Mubarak. — 2nd ed.
p. cm.
Includes bibliographic references.
ISBN 978-0-470-50533-5 (cloth)
1. Building industry—Management. 2. Building—Superintendence. 3. Production scheduling. I. Title.
TH438.4.M83 2010
690.068—dc22

2008045989

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

To the soul of my father, a brilliant scholar and a noble person.

He taught me the importance of knowledge, the art of teaching, and the spirit of giving. Best of all, he was a wonderful role model for me, being dedicated, altruistic, and humble.

To my mother, who always showed me the value of education and discipline.

To my wife, for her relentless encouragement, support, and patience during the years it took me to finish this book.

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Preface

Five years have passed since my book *Construction Project Scheduling and Control* came out. The response was more than encouraging. I received correspondence from several countries—comments, suggestions, requests for solutions, and simple complements. The simplicity was the most praised trait of the book. I was so happy and proud when the language editor (of the first edition) corrected me regarding an activity's *total float* in an example in the book. She was not a technical person but learned the Critical Path Method while linguistically reviewing my book.

During the past five years, I used my book in my seminars and college classes. I discussed it with my friends, colleagues, and students. I kept a log of all suggestions and corrections. I was thinking of the second edition just after the first one came out in 2004, just like a basketball coach thinking of the next season while in the current season. Although I was very happy and content with the way the book came out and was received, I discovered that there is no such thing as perfect human product. Imperfection is part of our nature as human beings, but we should think positively about it; there is always room for improvement. I had to combine satisfaction with ambition in completing this second edition with a strong conviction that the third edition is coming out in a few years.

One experience has added to my knowledge and the book—the overseas job I have held since July 2008. I could not imagine the pace and amount of construction in such a small place as Qatar. There are more tower cranes than you can count. Professional people came from all over the world, like a huge bouquet of flowers, with their diversity in education, culture, race, and language. Communications has been a challenge to say the least. Even though English is the official business language in the organization where I work, one soon realizes that English is not English! Forget about the difference in pronunciation and accents, forget about spelling of labor or

labour and program or programme; there are differences in the interpretation of technical terms and in the way we conduct business. To make it interesting, none of these ways is wrong. This situation is the cure for what I call the *background paradigm*, in which everyone believes he is right just because he was brought up this way! Then our cultures and ways of doing business clash and everyone believe the others are wrong! In many of these situations, there is no right and wrong; there are different ways. However, in a project management team, all must sing together with one common tune; what a challenge! Believe it or not, I enjoy every minute of this "clash of cultures" . . . I think of it like this: "one cubic meter of concrete mix, $100; one ton of steel, $600; one workday with 30 different nationalities, priceless!"

This edition contains many additions in almost every chapter and part of the book. Two new chapters have been added. One is on the Dynamic Minimum Lag (DML), a concept for a new logical relationship in CPM scheduling I recently developed. The other new chapter is on risk management in scheduling and project control.

Since the first edition, I have observed more qualitative interest in project scheduling in the professional and academic worlds. In particular, the Project Management Institute (PMI) has created a subsidiary in 2004 called College of Scheduling (PMI-COS), entirely dedicated to project scheduling issues—research, best practices, and standardization. In addition, the PMI recently created a new certification track in scheduling (Scheduling Professional, PMI-SP). I was invited to be in the committee that wrote its exam questions. Other organizations such as the Association for the Advancement of Cost Engineering, International AACEi, the American Institute of Architecture (AIA), the Construction Management Association of America (CMAA), the Associated General Contractors (AGC), and many others inside and outside the United States have also showed increased interest in scheduling and project control issues. This is coupled with the increasing role of CPM scheduling in delay and other claims, which made it an essential part of the required knowledge for judges, lawyers, and arbitrators. This is a clear indication of the importance of scheduling and project control in today's bigger and more complicated projects.

It was a grace from God to be able to finish this work. There are a lot of people to whom I owe a lot of gratitude. I would like to thank my friend and colleague Chris Carson for his tremendous help in the new risk chapter. My thanks also to attorney Barry Bramble for his help in updating and improving the claims chapter, which he originally co-authored, and to Mr. Earl Glenwright for his valuable input. Thanks to my colleagues Dr. Gui Ponce de Leon, Dr. Fredrick Plotnick, and Dr. Gunnar Lucko for their contributions to the "Other Scheduling Methods" chapter. Big thanks to Consolidated Contractors Company (CCC) of Athens, Greece, and its Qatar Director Mazen Karam, for providing me with nice pictures from their projects all over the world.

To all my readers—construction and other professionals, educators, and students: I would like to hear from you. If you have a question, suggestion, comment, or correction, please drop me an e-mail at CPMXPERT@gmail.com. I promise to make every effort to read and respond to every e-mail I receive. Such communications will elevate us in the pursuit of perfection.

Preface to the First Edition

The art of teaching requires two important components: knowledge of the subject and the ability to convey this knowledge to students. Having a love of the subject is a bonus that allows a teacher to take the classroom to an even higher level.

During my career as a structural engineer, as a construction professional, and as a professor, I have had to play many roles and wear many hats. There is no question that the different roles and different positions have provided me with rounded knowledge and a panoramic view of the construction industry. However, no subject has been more interesting and intriguing to me than scheduling and project control. During my teaching career, I acquired many books on this subject. Many of them are good or excellent books, but none has fulfilled my exact need. Some lack the detailed step-by-step approach, some have few examples and exercises, some are written by academicians with little real-world experience, and some deal with the subject of scheduling and project control as if it were still the 1970s or 1980s.

I was searching for a book that does the following:

- Addresses the need of the average student and details all steps clearly and without shortcuts
- Includes many solved and unsolved exercises that cover all the subjects in the book
- Relates to computer software programs used in the construction industry without making them the center of attention or overshadowing the theoretical principles
- Deals with precedence networks as the main and only viable CPM scheduling method, having coverage of arrow networks only as part of the evolution of scheduling
- Focuses on scheduling as part of the overall project management effort (rather than as just one chapter in a project management book)

Not having found such a book and after having taught scheduling for several years using four textbooks, I decided to write my own book. I started writing from scratch in early 2001. I also began living it: in my office, at home, when going to bed, in the shower, while driving the car, almost every waking moment. As ideas would come to mind, I would write them on a piece of paper or record them on my digital tape recorder. I did not want to let any idea escape me. Several experts also reviewed this book and provided me with invaluable critiques, and I made additional changes and improvements every time I read the text. Following is an outline of this textbook.

In chapter 1, planning, scheduling, and project control are defined, and the steps needed to build a schedule are described. In chapter 2, bar (Gantt) charts, the most common method used to display and report schedules, are introduced. This topic is revisited in chapter 9. Networks and the critical path method (CPM) are covered in the next four chapters. Chapter 3 covers arrow and node networks and their history, concepts, and structure. Chapter 4 addresses the CPM and its calculations. Chapter 5 covers precedence networks, an advanced form of node networks with its own calculations and concepts. I realize that this subject can become more complicated than field personnel or students can (or like to) handle. As a result, in this chapter, I offer two approaches: the simplistic approach, which leads to bottom-line results without becoming bogged in the details, and the detailed approach, for those who want to study the subject thoroughly. I further distinguish between continuous and interruptible activities, a subject I have not seen discussed clearly and sufficiently elsewhere in the literature.

Chapter 6 deals with resource allocation and leveling. This concept is explained clearly, more so in English than in mathematical terms. The mathematical model or algorithm for resource leveling is not discussed because it is complicated and unnecessary and because most schedulers never refer to it. Powerful computers and software have made this function feasible and practical.

Scheduling would be worthless without updating and project control, so chapter 7 covers this important subject. Chapter 8 addresses an interesting topic: schedule compression and time-cost trade-offs. In chapter 9, I explain some commonsense ideas about reports and presentations, in the context of scheduling. In chapter 10, I address scheduling as part of the project management effort. This chapter sheds some light on the interrelationships among scheduling, estimating, and other components of construction project management.

Chapter 11 covers a few other scheduling methods, such as the program evaluation and review technique (PERT) and the linear scheduling method (LSM). Chapter 12 provides brief coverage of delay claims, their avoidance, and their resolution. The chapter was written to provide an idea on the subject, and not as an in-depth reference.

Appendix A contains a computer project with multiple assignments that correspond to all subjects discussed in the book. Appendix B contains a few sample reports that the author created using Primavera P3e and SureTrak Project Manager software.

Throughout the book, not only there are illustrated examples for almost every concept, but also end-of-chapter exercises. Such exercises include both numerical type exercises (covering the spectrum of difficulty) and conceptual questions. The latter

type contains mostly short, essay-type questions. Multiple-choice questions are not included because students need to know what the terms and definitions of construction scheduling are, rather than what they are not. Also, several exercise projects are provided so that students can use them for a computer project.

My intent was to introduce a scheduling book suitable for the 21st century. I hope that I have succeeded; however, I am sure that readers—construction professionals, educators, and students—will have suggestions and criticisms of this text. I encourage readers to send their corrections and suggestions to the publisher so that I can include any necessary changes in future editions.

In preparing this book, I relied on the help of many friends and associates. To them, I owe my gratitude. I give specific thanks to the reviewers of this text for their helpful comments: Michael J. Cook, University of Florida; Rocky Gerber, University of Washington; Charles R. Glagola, University of Florida; James L. Jenkins, Purdue University; David Leo Lickteig, Georgia Southern University; and James Stein, Eastern Michigan University. Likewise, thanks to Attorney Barry Bramble, who provided me with his invaluable contribution to chapter 12, Construction Delay Claims.

Construction Project Scheduling and Control

Chapter 1

Introduction

Interstate 4 and 17/92 intersection in Sanford, Florida

PLANNING AND SCHEDULING

Planning and *scheduling* are two terms that are often thought of as synonymous. However, they are not. Scheduling is just one part of the planning effort. The term *planning* is used in many ways and different contexts. We commonly hear about *financial* planning, such as retirement planning and college education planning. Although this type of planning may include other aspects (such as what to do after retirement or which college to choose for your child), the main focus is on finance. Governments, as well as large corporations, have planning units or teams in almost every department. At the individual level, a young person may have plans for marriage, a career, and so forth. However, in the context of this book, the term *planning* is restricted to meaning project planning, with an emphasis on construction projects.

What Is a Project? Before we define project planning, we need to define a project. The Project Management Institute (PMI 2008) defines a **project** as "a temporary endeavor undertaken to create a unique product, service, or result" (p. 434). The key words in this definition are *temporary* and *unique*: any project must have a starting point and an ending point, and it must have a deliverable product or service that is unique. As a generic example, a secretary of education's saying "We need to improve our students' SAT scores" does not constitute a project. However, saying "We need to improve our students' SAT scores by an average of 15 points in 5 years" may qualify as a project.

Some government agencies have specific but ongoing work that they call a project, such as maintenance of a certain facility or park compliance with the Americans with Disabilities Act. Technically, these are not projects because they have no well-defined deliverable product or service and starting and ending points. Each could be called a *program*, instead, with several projects inside each program. Basically, we need to distinguish among:

- *Program*: A "program" may mean different things to different people depending on the context. In project management, a program—usually—is a group of related projects and/or services intended to meet a common objective and usually managed by one entity. A program could also indicate a large and complex project that is divided into several projects for more effective management. The PMI defines a program as "A group of related projects managed in coordinated way to obtain benefits and control not available from managing them individually. Programs may include elements of related work outside of the scope of the discrete projects in the program." (PMBOK 2008)

Programs may be:

- Temporary/one-time programs: For example, the City of London (UK) may have all the construction projects for the 2012 Summer Olympics under one program. Once this program culminates with the completion of its projects; by the opening of 2012 Summer Olympic Games, it will be completed and closed. The maintenance of these facilities, later on, is a different matter.

- Ongoing (usually periodic/annual) programs: These include projects such as road maintenance and storm water programs for a public works department in many municipalities. Many private and public institutions have maintenance programs for their existing facilities. Such a program usually has annual budget and covers numerous small projects—as many as the budget allows. The program usually lives as long the facility does.

One important note: In the UK, as well as in some other countries that use British terminology, the schedule (timeline) of the project is called program (spelled programme). This is *not* the program that we are discussing.

- *Portfolio*: This is a group of projects, not necessarily related or dependent, usually under one project manager or department. The PMI defines it as "A collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives. The projects or programs of the portfolio may not necessarily be interdependent or directly related." (PMBOK 2008)
- *Project*: Defined above.
- *Subprojects*: These are segments of the original project that are divided according to specialty, responsibility, phase, area, or other criteria. To the person in charge of a subproject, the subproject is a project, except that he/she has to consider not only the internal relationships among its activities but the external relationships as well (with activities in other subprojects in the same project). For example, in a residential or commercial development project, building the infrastructure may be regarded as a subproject. In fact, building the sewer system in the development can be a subproject (to the entire development project) or even a sub-subproject (to the infrastructure subproject).

Are Projects Unique? Some people may think of two construction projects as identical just because they have the same design. In project management, we may have similar projects, but every project is unique. Differences may come from a difference in location (soil type, weather conditions, labor market, building codes, unforeseen conditions, etc.), in management type and experience, or in circumstances (and how much Murphy's Law is involved).

Project planning has been defined as "the process of choosing the one method and order of work to be adopted for a project from all the various ways and sequences in which it could be done" (Antill and Woodhead 1990, p. 8; Callahan, Quackenbush, and Rowings 1992, p. 2). The PMI defined the planning process in the PMBOK (4^{th} edition, 2008) as "Those processes performed to establish the total scope of the effort, define and refine the objectives, and develop the course of action required to attain those objectives". Project planning serves as a foundation for several related functions, such as cost estimating, scheduling, project control, quality control, safety management, and others.

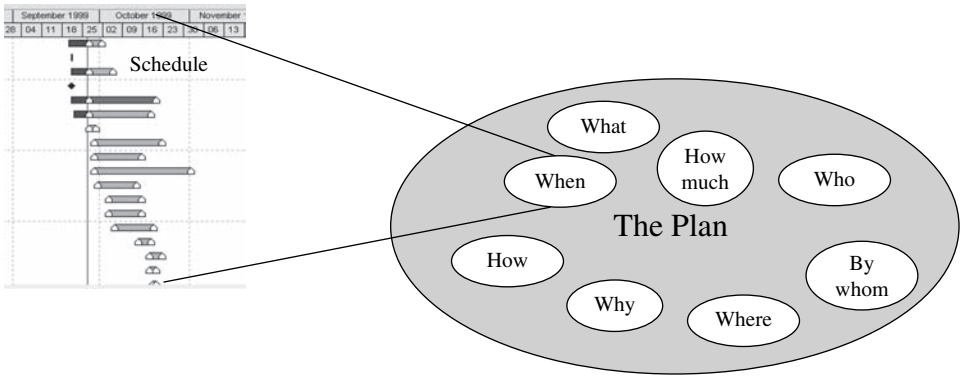

Figure 1.1 Planning and scheduling

Scheduling is the determination of the *timing* and *sequence* of operations in the project and their assembly to give the overall completion time. As mentioned previously, scheduling focuses on one part of the planning effort.

Project planning answers the questions *What* is going to be done? *How*? *Where*? By *whom*? and *When* (in general terms, the project's start and end)? Scheduling deals with *when* on a detailed level.

In fact, scholars have generally separated planning from scheduling "CPM separates planning and scheduling, and once project information is collected and expressed as a network plan and activity time estimates assigned, CPM calculations can be made. Planning ceases and scheduling starts when the first computation is performed that shows a project duration. The project duration is then compared with the desired schedule and scheduling begins." (O'Brien and Plotnick, 2009, p. 417)

To get an idea about the relationship between project planning and scheduling, assume that you are planning a family vacation "project" for next summer. Your *plan* may include considerations such as these:

- Who will go on the trip?
- Which places do you want to visit? (You would like to visit many places, but your time and monetary resources are limited.)
- What is the time frame for the vacation (just the starting and ending dates)?
- What is the total budget for the "project" (including the contingency you did not tell other family members about)?
- What types of activities do you want to participate in during the trip (sharp differences among the family members)?
- What means of transportation do you plan to use (your car, a rental car, air, train, bus, RV, bicycles, etc.)?
- What other issues, such as accommodations, food, and clothing, need to be addressed?

The project *schedule* is simply the itinerary, such as this:

- Leave home in Tampa, Florida, on June 8, 2010.
- Arrive in Panama City, Florida, on June 8, 2010.
- Leave Panama City on June 15, 2010.
- Arrive in Atlanta, Georgia, on June 15, 2010.
- Leave Atlanta on June 22, 2010.
- Arrive in Gatlinburg, Tennessee, on June 22, 2010.
- Return home to Tampa on July 7, 2010.

Note that not only the plan and the schedule are related, but also many of the elements of the plan are interrelated. For example, most of the choices in the plan (length of stay, type of accommodations, means of transportation, type of activities, food, etc.) affect the budget. Since different means of transportation have longer time durations than others, they may affect not only the cost but the schedule as well. Clearly, a lack of clarity of scope before the project starts may lead to heated arguments and dissatisfaction. In real projects, it may lead to huge budget overruns, schedule delays, and different parties' dissatisfaction. Therefore, it is important to have a clear understanding of the project's scope (objectives), and decide who the ''project manager'' is. Many issues are at stake in this example, but demonstrating the concepts of planning and scheduling is our objective.

In the context of construction projects, a typical plan for an office building project may include the following:

- A *scope definition*, such as a five-story building for commercial use (offices) with a total area of about 30,000 square feet. The location is also part of the planning, although, in some cases, the exact location may be selected later or a few sites are mentioned as candidates.
- A *schematic* or *conceptual design*. This is not a must but helps one to visualize the project. The final design may later differ significantly.
- A *budget number* (e.g., $6 million). The planner must be aware of all project-related expenses, such as the cost of land, permits, design fees, construction, and so forth.
- A *time frame* (i.e., when the project is expected to start and end).
- *Other pertinent information* that may be used to justify the project or clarify some of its aspects. If an investor is doing the planning, a **pro forma** helps predict the rate of return and helps in making the decision whether or not to build the project.

PMI defines **project management plan** as a ''formal, approved document that defines how the project is executed, monitored and controlled. It may be summary or

detailed and may be composed of one or more subsidiary management plans and other planning documents. The objective of a project management plan is to define the approach to be used by the project team to deliver the intended project management scope of the project." (PMBOK 2008)

The project manager creates the project management plan following input from the project team and key stakeholders. The plan should be agreed on and approved by at least the project team and its key stakeholders. It is a good practice, used by professional project management and consulting firms, to have a formal project management plan approved in the early stages of the project and applied throughout the project. Many owners (clients) require the contractor to submit a project management plan and have it approved as part of the contract documents.

PROJECT CONTROL

Once a project starts, certain aspects can easily deviate or go astray. This deviation can be overspending, a schedule slippage, a departure from the objective/scope, or something else. It is of utmost importance to know—at all times—where you stand in relation to where you planned to be (the baseline). If you find yourself behind schedule or over budget, you must know why and then take corrective action to get back on track or, at least, minimize the deviation. If the deviation is positive (i.e., the project is ahead of schedule or under budget), actual performance was probably better than that expected in the baseline plan. This process exemplifies **project control.** Although the concept of project control covers all aspects of the plan (budget, schedule, quality, etc.), our main focus in this book is on schedule and budget control, which are related. (Extensive coverage of project control is provided in chapter 7.)

WHY SCHEDULE PROJECTS?

There are several parties involved in any project (stakeholders). They all need and benefit from project scheduling but from different perspectives. Following is a group of reasons for why project scheduling is needed, from two different perspectives: contractors and owners.

Contractors need project scheduling to:

1. *Calculate the project completion date*: In most construction projects, the general contractor (GC), including subcontractors and other team members, is obligated to finish the project by a certain date specified in the contract. The contractor has to make sure that his or her schedule meets this date. Some contracts contain clauses for penalties for finishing the project later than contractually required and/or incentives (financial or other) for finishing earlier. Also, the schedule may show the stage of **substantial completion**,

when the owner may start occupying and using the facility while the contractor is still doing some final touches.

2. *Calculate the start or end of a specific activity*: Specific activities may require special attention, such as ordering and delivering materials or equipment. For instance, the project manager may want special and expensive equipment to be delivered just in time for installation. Long-lead items may have to be ordered several months in advance. Delivery of very large items may need coordination or a special permit from the city so that such delivery does not disrupt traffic during rush hour. The schedule must show such important dates.
3. *Coordinate among trades and subcontractors, and expose and adjust conflicts*: In today's construction, the GC's role is mostly to coordinate among different subcontractors. The responsibility of the GC may be to allocate the time of use of a tower crane among subcontractors or just to ensure that adequate work space is available for all subcontractors. These tasks are in addition to coordinating logical relationships such as when a subcontractor's activity depends on the completion of another subcontractor's activity. For example, the drywall contractor cannot start until the framing has been done; once the drywall is installed, the painter can start painting; and so on.
4. *Predict and calculate the cash flow*: The timing of an activity has an impact on the cash flow, which may be an important factor for the contractor (or the owner) to consider. The contractor (or the owner) must know his or her total spending in any month or time period. He or she may delay the start of certain activities, within the available *float* (this term is explained subsequently) to make sure that the cash flow does not exceed a certain cap.
5. *Improve work efficiency*: By properly distributing workers and equipment and having efficient materials management (which is explained in chapter 6), the GC can save time and money.
6. *Serve as an effective project control tool*: Project control must have a solid and sound base with which current performance can be compared. Project control is achieved by comparing the actual schedule and budget with the baseline (as-planned) schedule and budget (this subject is explained in chapter 7).
7. *Evaluate the effect of changes*: **Change orders** are almost inevitable, but well-planned projects may have few or minor change orders. Change orders may come in the form of directive, that is, an order to the contractor to make the change, or request for evaluation before authorization. This change may be an addition, a deletion, or a substitution. Change orders may have an impact on the budget, schedule, or both. Cost estimators estimate the cost of change orders (including the impact on the overhead cost as a result of the schedule change), but schedulers calculate the impact of the change on the project schedule. It is the contractor's responsibility to inform the owner on such impact and obtain his/her approval on the change to the budget and/or schedule.

8. *Prove delay claims*: Construction **delay claims** are common. Contractors must be able to accurately prove their claims against owners (or other parties) using project schedules. In most cases, only a **critical path method (CPM)** schedule can prove or disprove a delay claim, which can be a multimillion dollar one.

Project owners and developers need project scheduling to:

1. *Get an idea on project's expected finish date*: Before an owner demands that the general contractor (GC) complete the project by a certain date, he/she needs to make sure that this is a feasible and reasonable date. This date is calculated by a CPM schedule prepared either by the owner or by the designer or other consultant hired by the owner. This date is also important to the owner, even before selecting a contractor, to conduct feasibility studies and financial planning.
2. *Ensure contractor's proper planning for timely finish*: Owners may demand a project schedule from the prospective or bidding contractor, however, it is very important for the owner to review such schedule and make sure that it is reasonably accurate and realistic. Owner's approval of contractor's prepared schedule may imply a liability on the owner's side.
3. *Predict and calculate the cash flow*: The owner is obligated to make timely progress payments to the contractor and other parties along the life of the project. Failure to do so not only may delay the project and/or incur additional cost but it also may—at certain point—be deemed a breach of contract.
4. *Serve as an effective project monitoring tool*: Both owner and contractor must monitor progress of work and compare actual progress (schedule and cost) with the baseline (as-planned) schedule and budget. The contractor uses this process to detect and correct any deviation and also to prepare progress payments. The owner uses this process to verify actual work progress and contractor's payment requests.
5. *Evaluate the effect of changes*: Owners may desire or require change orders. In many instances, owners don't expect or fully appreciate the impact these change orders may have on the schedule and/or budget. It is a wise idea for an owner to find out this impact before making a decision regarding such change order. It is also recommended that owners analyze the contractor's assessment of the change order to make sure that it is fair and reasonable.
6. *Verify delay claims*: Owners use CPM schedules to analyze, verify, and/or dispute contractors' delay claims. Although most delay claims are initiated by contractors against owners, it is possible to reverse roles and have an owner's claim against the contractor, and/or have other parties involved. In either case, a CPM schedule is vital for the owner to prove his/her case.

Other parties involved in the project may also need a CPM schedule, such as the designer, project management consultant, and financial lending institution.