CONSTRUCTION PROJECT SCHEDULING AND CONTROL

3 THIRD EDITION

SALEH MUBARAK

WILEY

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Preface

This is the third edition of *Construction Project Scheduling and Control.* I am very pleased with its continuous success. The book has become popular throughout the world, both in paper and in digital form. I continuously receive correspondence—comments, suggestions, requests for instructional materials (instructor support materials including an instructor manual and PowerPoints can be accessed by visiting http://www.wiley.com/buy/9781118846001 and clicking on the "More Information About this Book" link), and compliments. The most praised traits of the book are its simplicity, comprehensiveness, and practical examples. 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 had no technical background but had learned the critical path method while linguistically reviewing my book!

During the past nine years, I have been using my book in professional seminars and college classes. I have discussed it with my friends, colleagues, and students. I have always kept a log of all suggestions and corrections. I started thinking about the second edition just after the first edition was published in 2004 and about the third edition just after the second edition was published in 2010. I have modified the definition of the critical path after so many readings and discussions with experts and colleagues. I think I have now the most accurate definition in all of the literature available. Is it possible that I modify the definition in the future? Absolutely!

Although I was very happy and content with the way the book came out and was received, I believe there is no such thing as the perfect human product. Imperfection is part of human nature, but we should think of it positively: there is always room for improvement. I have had to parallel my satisfaction and ambition in completing this third edition with a strong conviction that the fourth edition will be coming out in a few years. In my professional seminars and college courses, even though the course or seminar may be the same, I make updates and adjustments every time I teach it.

I believe in continuous improvement and in the saying, "My today must be better than my yesterday, and my tomorrow must be better than my today."

One experience has added to my knowledge and the book—the overseas jobs that I have held between 2008 and 2014. 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. Professionals come from all over the world, like a huge bouquet of flowers, with their diversity in education, culture, race, and language. Communication has been a challenge, to say the least. Even though English is the official language for doing business in most organizations there, one soon realizes that English is not English! Forget about the difference in pronunciation and accents, forget about the spelling of *labor* versus *labour* and *program* versus *programme;* there are differences in the interpretation of technical terms and in the way business is conducted. To make it interesting, none of these differences is wrong. This situation is the cure for what I call the ***background paradigm***, in which everyone believes he or she is right just because he was brought up this way! Then our cultures and ways of doing business clash, and everyone believes the other persons are wrong! In many of these situations, there is no right and wrong; there are just different ways of doing things. However, in a project management team, all must sing together in harmony with one common tune—what a challenge! Keep in mind, our field is an empirical, not an exact, science! 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. One new chapter (Chapter 15) has been added on "Building Information Modeling (BIM) and scheduling." BIM's popularity has been increasing rapidly due to its advantages that new hardware and software technology have made possible. I have also added "Tip boxes" in almost every chapter.

Since the first edition, I have observed more qualitative interest in project scheduling in the professional and academic disciplines. In particular, the Project Management Institute (PMI) has created a certification track in scheduling (Scheduling Professional, PMI-SP) in 2008 (the author served in the committee that prepared the first SP exam), and the AACE International has its own Planning & Scheduling Professional (PSP) certification. Other professional organizations, such as the American Institute of Architecture (AIA), the Construction Management Association of America (CMAA), the Associated General Contractors (AGC), the UK's Chartered Institute of Building (CIOB), and many others inside and outside the United States have also showed increased interest in scheduling and project control issues. This, coupled with the increasing role of project scheduling (using the critical path method) in delay and other claims, has made it an essential part of required knowledge for judges, lawyers, and arbitrators. This is a clear indication of the importance of project scheduling and control for today's bigger and more complicated projects.

It was a grace from God to have been able to finish this work. There are several people to whom I owe a lot of gratitude. I would like to thank Dr. Onur Tokdemir and Ms. Acelya Yildiz for their valuable contribution to the new chapter on BIM.

I also would like to thank attorney Barry Bramble and my colleague Chris Carson for updating Chapters 13 ("Construction Delays and Other Claims") and 14 ("Schedule Risk Management"), which they originally coauthored. Thanks to my colleagues Dr. Gui Ponce de Leon, Dr. Fredrick Plotnick, and Dr. Gunnar Lucko for their contributions to Chapter 11, "Other Scheduling Methods." Thanks also to Al Mazaya Holding Company in Kuwait and its Chief Projects Officer, Dr. Abdulaziz Jarkas, for providing me with wonderful pictures from their projects.

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 send me an e-mail at CPMXPERT@gmail.com. I promise to make every effort to read and respond to every e-mail that I receive. Such communication 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.

Contents

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 these types 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. Government organizations, as well as large corporations, have planning units or teams in almost every department. All plans in the individual units must be aligned with the organization's "*strategic plan,*" which is the long-term plan for the organization itself in terms of operations and growth. 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 mean 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) defines a **project** as "a temporary endeavor undertaken to create a unique product, service, or result" (PMI, 2013, p. 573). 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, service, or result that is unique. As a generic example, a secretary of education 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 five years" may qualify as a project. Another example: a newlywed couple may decide on saving money to buy a house. This is not a project, but saying "we are planning to save $50,000 in the next five years" may qualify as a project.

Tip Box 1.1

Every project must have a start point, a finish point, and a deliverable.

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 or other regulation. Technically, these are not projects because they have no well-defined deliverable product or service and/or starting and ending points. Each could be called a *program*, instead, with several projects within each program. Basically, we need to distinguish between a program and a project:

- *Program*: A *program* may mean different things to different people, depending on the context. In project management, a program usually is a group of