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.

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

related projects and/or services intended to meet a common objective and usually managed by one entity. A program can 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, subprograms, and program activities managed in coordinated way to obtain benefits not available from managing them individually" (PMI, 2013). Programs may include elements of related work outside the scope of the discrete projects in the program.

Programs may be temporary/one-time or ongoing:

- *Temporary/one-time programs*: For example, the City of Rio de Janeiro (Brazil) may include all of the construction projects for the 2016 Summer Olympics under one program. Once this program culminates with the completion of the projects, by the opening of the 2016 Summer Olympic Games, it will be completed and closed. However, the future maintenance of these facilities 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 programs usually have an annual budget and cover numerous small projects—as many as the budget allows. The programs usually live as long the facility does.

One important note: in the United Kingdom, 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 same type of program that we are discussing.

- *Portfolio*: This is a group of projects, not necessarily related or dependent, that is, usually under one project manager or department. The PMI defines it as "projects, programs, subportfolios, and operations managed as a group to achieve strategic objectives" (PMI, 2013).
- *Project*: Defined earlier.
- *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 the person has to consider not only the internal relationships among the 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).

  Figure 1.1 *demonstrates the structure of programs, portfolios, projects; and the relationships among them.*

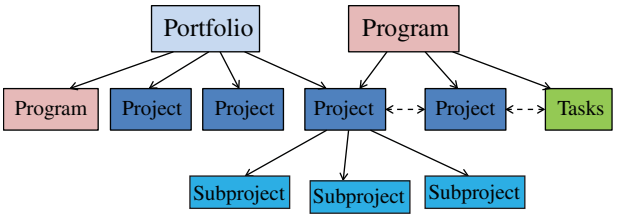

Figure 1.1 Programs, Portfolios, and Projects

Are Projects Unique?

Some people may think of two construction projects as being identical just because they have the same design. In project management, we may have similar projects, but every project is unique. Differences may occur because of location (soil type, weather conditions, labor market, building codes, unforeseen conditions, etc.), labor skill level, management type and experience, or for other circumstances (and how much Murphy's Law was involved).

> **Tip Box 1.2**
>
> Just because two projects have exactly the same design and perhaps were built by the same contractor doesn't make them *identical*. They are similar but differences can come from site, location (building code, weather, etc.), workforce, execution conditions, and so on.

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 defines the Planning Process Group as "those processes required to establish the scope of the project, refine the objectives, and define the course of action required to attain the objectives that the project was undertaken to achieve" (PMI, 2013). Project planning serves as a foundation for several related functions, such as cost estimating, scheduling, project control, quality control, safety management, and others.

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*? *How much*? *Where*? By *whom*? *When?* (in general terms, the project's start and end). Scheduling deals with *when* on a detailed level. Figure 1.2 graphically demonstrates this concept. (See Figure 1.2.)

In fact, scholars have generally separated planning from scheduling: "CPM separates planning and scheduling, and once project information is collected and expressed

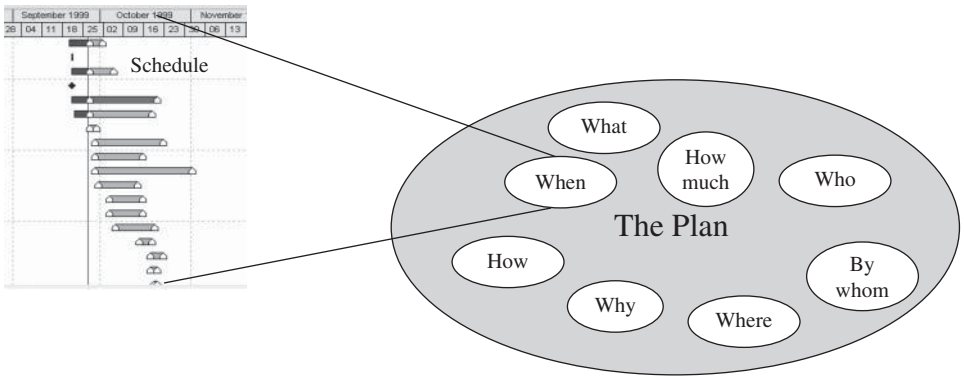

Figure 1.2 Planning and scheduling

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 the following:

- 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? (Are there sharp differences among the family members?)
- What means of transportation do you plan to use (your car, a rental car, air, train, bus, RV, etc.)?
- What other issues, such as accommodations, food, and clothing, need to be addressed?

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

- Leave home in Tampa, Florida, on June 8, 2015.
- Arrive in Panama City, Florida, on June 8, 2015.
- Leave Panama City on June 15, 2015.
- Arrive in Atlanta, Georgia, on June 15, 2015.

- Leave Atlanta on June 22, 2015.
- Arrive in Gatlinburg, Tennessee, on June 22, 2015.
- Return home to Tampa on July 7, 2015.

Note that not only are the plan and the schedule related, but also many of the activities and elements of the plan are interrelated. For example, most of the choices in the plan (length of stay, type of accommodations, type of activities, means of transportation, food, etc.) affect the budget. Since different means of transportation have longer time durations than others, they may affect not only the cost but also the schedule. Clearly, a lack of clarity of scope before the project starts may lead to heated arguments and dissatisfaction among team members later on. In real projects, it may lead to huge budget overruns, schedule delays, different parties' dissatisfaction, and a potential loss of business. Therefore, it is important to have a clear understanding of the project's scope, its constraints and requirements, and the decision-making process.[1] Many issues are at stake in this example, but demonstrating the concept of planning and scheduling is the objective.

It has been proven that good planning results in a high "rate of return" in terms of saving time, money, effort, change orders, claims and disputes, and headaches. In fact, there are many construction professionals who assert that there is an inverse relationship between the time of planning and the time of execution. Many owners rush the design and construction process because "they don't have time for planning." In fact, this is, in most cases, self-defeating and causes additional delays, costs, and headaches. An old carpenters' saying, "Measure twice and cut once," embodies this concept well.

Tip Box 1.3

Plan first: Measure twice and cut once!

Project Management Plan:

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 may be mentioned as candidates.
- A *schematic* or *conceptual design*. This is not a must but will help in visualizing the project. Also, deciding on the level of finish (economy, average, or luxury)

[1] There is more discussion on this issue in Chapter 10.

will help in making financial arrangements. 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 as to whether or not to build the project.

PMI (PMI, 2013) defines a **project management plan** as "the document that describes how the project will be 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.[2] It captures the entire project, covering all project phases, from initiation through planning, execution, and closure.

The level of details of the project management plan depends on several factors: the purpose of the plan, the timing of the plan, and the detailed information available (which is, in part, a function of the timing).

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 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.

Many professional organizations have an office dedicated to the project management planning and effort, called a *project management office (PMO)*, which is defined by the PMI as "an organizational structure that standardizes the project-related governance processes and facilitates the sharing of resources, methodologies, tools, and techniques" (PMI, 2013).

Tip Box 1.4

Have you ever thought of applying project management principles to your own life?

[2] This paragraph was taken from the PMI *PMBOK Guide,* 5th edition, 2013.

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 the utmost importance to know at all times where you stand in comparison with where you planned to be (the baseline) at this time. If you find any variance, you must know the amount and causes of the variance and then take corrective action to get back on track or, at the very least, to minimize the variance. If the variance 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 may cover 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 use project schedules but from different perspectives. Following is a group of reasons why project schedules are 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 that is specified in the contract. The contractor has to make sure that the schedule meets this date or otherwise has to accelerate the project. 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 need 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 the 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 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 provided to all workers and personnel on-site. 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 baseline 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 (CO)**[3] are usually inevitable, but well-planned projects may have few or minor ones. Change orders may come in the form of a directive, that is, an order to the contractor to make a change, or a 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 of such an impact on the budget or schedule and obtain the owner's approval.
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 of a project's expected finish date*: Before an owner demands that the GC complete the project by a certain date, the owner needs to make sure that it is a feasible and reasonable date. This date is calculated by a CPM schedule, prepared by the owner or the designer, or a 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.

[3] Also called *variation orders* in other countries, such as the United Kingdom.