Mario Vanhoucke

Integrated Project Management Sourcebook

A Technical Guide to Project Scheduling, Risk and Control

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Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it.

Samuel Johnson

Preface

This book is intended to be an Integrated Project Management Sourcebook for students of any project management (PM) course focusing on the integration between baseline scheduling, schedule risk analysis, and project control, known as *Dynamic Scheduling* or *Integrated Project Management and Control*. It contains a set of +70 articles that are also available online at www.pmknowledgecenter.com. The introduction of the book contains an overview article of the Project Management Knowledge Center with references to a PM bookstore, software tools, research results, and much more material relevant to the reader. The main body of this book contains articles on *baseline scheduling*, *risk analysis*, and *project control*. Each individual article focuses on one particular topic, and links are provided to the other articles (chapters) in this book. Almost all articles are accompanied with a set of questions (unlike the articles, these questions cannot be found online), for which the answers are provided at the end of this book.

This book has been written in the sunlight of Lisbon during my 4-month stay at the city of light. While artists say that light is all important to creating a masterpiece, I just think back on it as a period where I enjoyed writing in my apartment at Beco da Boavista and on the terraces of Jardim da Praça Dom Luís I (my favorite one, I called it the red terrace), Praça do Comércio, and Portas do Sol but also on the Miradouro de Santa Catarina, the city beach of Cais do Sodré, and of course at Universidade Aberta de Lisboa. In fact, it is my stay at the city that has become the masterpiece, while the book is simply the result of hard work in complete isolation from all Belgian distractions.

It goes without saying that the writing of such a manuscript is not an individual work, but is done in collaboration with people willing to help in many ways. Thank you to friend and colleague José Coelho for the many work meetings with fruitful and enriching discussions at various places in Lisbon. Thank you to Jordy Batselier, Jeroen Burgelman, Danica D'hont, Louis-Philippe Kerkhove, Pieter Leyman, Annelies Martens, and Vincent Van Peteghem for helping me with providing a set of questions and for checking the calculations throughout the many examples given in each chapter. Thank you to Mathieu Wauters for proofreading most of the articles. Thank you Louis-Philippe Kerkhove once again for setting up

a shared online correction system for our research group and for double-checking the questions of all the articles over and over again. Thank you to Tom Van Acker for providing the IT technology to put all the articles online. Thank you to Gaëtane Beernaert for supporting me in extending this work from an online learning tool to a complete integrated manuscript.

Lisbon, Portugal Mario Vanhoucke
August 2015

Contents

Chapter 1
Introduction

Welcome to PM Knowledge Center[1]

Project baseline scheduling, risk analysis and project control are crucial steps in the life of a project. The project manager uses the project schedule to help planning, executing and controlling project activities and to track and monitor the progress of the project. A major component of a project schedule is a work breakdown structure (WBS). However, the basic critical path method (CPM) schedules, or its often more sophisticated extensions, are nothing more than the starting point for schedule management. Information about the sensitivity of the various parts of the schedule, quantified in schedule risk numbers or of a more qualitative nature, offers an extra opportunity to increase the accuracy of the schedules and might serve as an additional tool to improve project monitoring and tracking. Consequently, project scheduling and monitoring/control tools and techniques should give project managers access to real-time data including activity sensitivity, project completion percentages, actuals and forecasts on time and cost in order to gain a better understanding of the overall project performance and to be able to make faster and more effective corrective decisions. All this requires understandable project performance dashboards that visualize important key project metrics that quickly reveal information on time and cost deviations at the project level or the activity level. During monitoring and tracking, the project manager should use all this information and should set thresholds on the project level or on lower WBS levels to receive warning signals during project execution. These thresholds serve as triggers to take, when exceeded, corrective actions.

This triangular role of a project schedule is often labeled as *dynamic scheduling* (see Fig. 1.1) to highlight the need and ability of project scheduling software

[1]This section is also available as an article entitled "Dynamic scheduling: Welcome to PM Knowledge Center" published online at PM Knowledge Center.

M. Vanhoucke, *Integrated Project Management Sourcebook*,
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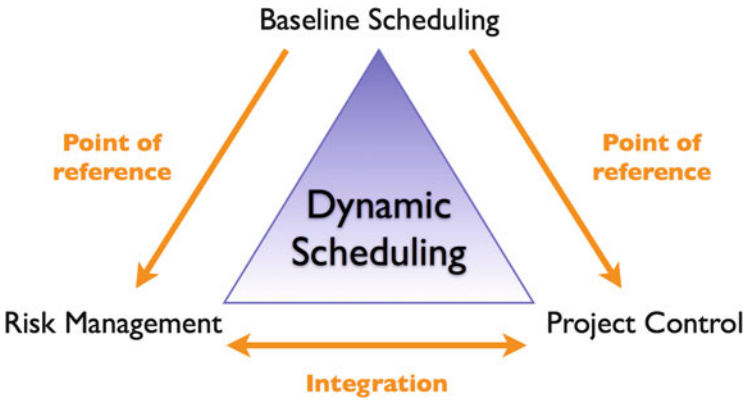

Fig. 1.1 Dynamic scheduling: the baseline schedule, risk management and project control triangle

to dynamically create a baseline schedule environment that provides information during project execution and that can be easily adapted using the new information during project monitoring and tracking. Consequently, the three dimensions of dynamic scheduling can be summarized as follows:

- Baseline schedule construction: A project baseline schedule visualized in a Gantt chart acts as a point of reference in the project life cycle. It should especially be considered as nothing more than a predictive model that can be used for resource efficiency calculations, time and cost risk analysis, project tracking and performance measurement, and so on (see section "BS1: An Introduction to Baseline Scheduling" on page 9).
- Schedule risk analysis: When management has a certain feeling of the relative sensitivity of the various project activities on the project objective, a better management's focus and a more accurate response during project tracking should positively contribute to the overall performance of the project. Through the use of buffers inserted into the baseline schedule, the project is better protected against unexpected delays and corrective actions can be restricted to a minimum (see section "RA1: An Introduction to Risk Analysis" on page 109).
- Project control: Using dynamic information during project progress to improve corrective action decisions is the key target of project monitoring and control. The performance information obtained through EVM will be dynamically used to steer the corrective action decision making process and improve the overall success of the project (see section "PC1: An Introduction to Project Control" on page 197).

This book acts as an Integrated Project Management Sourcebook on dynamic scheduling, integrating these three dimensions in three different parts of the book. It is considered to be part of the Project Management Knowledge Center (further abbreviated as PM Knowledge Center or PMKC) that is the topic of this chapter.

The purpose of PM Knowledge Center is to act as a Project Management guide for students, lecturers and professionals interested in the field of Dynamic Scheduling. All topics described in the articles are based on research done at Ghent University (Belgium). Additionally, the aim of PMKC is to share knowledge and invoke interest in Project Management. To that purpose, a number of tools are available, that are summarized along the following lines.

- ORASTalks app: Stimulate interaction
- ProTrack: Dynamic scheduling on your desktop
- Business Game: Learning by doing
- Bookstore: Literature for students and professionals
- P2 Engine: Advancing the state-of-the-art knowledge
- Research: Project Management research

ORASTalks

The main purpose of PM Knowledge Center is to interact with our audience consisting of undergraduate and graduate students, MBAs and practitioners. All summary articles of PM Knowledge Center in this book are therefore also freely available from the website www.pmknowledgecenter.com. In order to get and stay in contact with our PMKC audience, a free mobile app has been developed. ORASTalks is an app that aims at bringing students together to offer them a central place for their course content, to provide them with additional background information and to bring them in contact with interested professionals. OR-AS is an acronym for "Operations Research—Applications and Solutions" and develops software Applications and Solutions for academia and business based on a well-balanced combination between academic knowledge and practical experience. It serves as a bridge between the academic environment of our university and MBA students and the business world that they will soon (re-)discover after their graduation. The specific approach to improve and optimise business processes consists of data analysis, simulation and optimisation using state-of-the-art tools and techniques, followed by the implementation and validation. The field of Operations Research is applicable to many complex business processes. Special attention will be devoted to Integrated Project Management and Control using well-known as well as novel project management tools and techniques. More information can be found at www.or-as.be/orastalks.

ProTrack

ProTrack 3.0 is a complete redesigned version of the smart version of ProTrack 2.0. Its integration with PM Knowledge Center and its strong focus on the integration of

baseline scheduling, risk analysis and project control makes it yet a stronger learning tool to stimulate interaction between researchers, students and practitioners in the field of project management and dynamic scheduling. Go to www.protrack.be, buy, interact and. . . enjoy! More information can be found at www.protrack.be.

Business Game

The Project Scheduling Game (PSG) is an IT-supported simulation game to get acquainted with dynamic project scheduling using the critical path method (CPM). The critical path method involves a time/cost trade-off in project activities and require the construction of a project baseline schedule within a predefined project deadline and budget. The uncertainty during project progress disturbs the original baseline schedule and requires interventions to bring the project back on track. More information can be found at www.protrack.be/psg.

Bookstore

The themes discussed in PM Knowledge Center are the result of research projects at Ghent University and Vlerick Business School and the development of a commercial software tool ProTrack at OR-AS. Currently, three books published by Springer are available (see Fig. 1.2 or www.or-as.be/books):

- Integrated Project Management and Control: First comes the theory, then the practice: A summary book on Earned Value Management and Schedule Risk

Fig. 1.2 PMKC bookstore: three books published by Springer

Fig. 1.3 PMKC bookstore: the three editions of "The Art of Project Management"

Analysis, containing example projects and reports, as well as an overview of the P2 Engine tool.

- Project Management with Dynamic Scheduling: Baseline scheduling, risk analysis and project control: An overview book on the three main themes of dynamic scheduling, containing overview chapters, cases studies and a tutorial for the ProTrack software tool.
- Measuring Time: Improving project performance using Earned Value Management: A project control research study awarded by the Belgian chapter of the Project Management Institute (PMI-Belgium) and the International Project Management Association (IPMA).

A fourth book is published as a free online pdf at www.or-as.be/books/work_and_passion. The first edition is published in 2014 and ever since a yearly update has been put online, resulting in the third edition in 2015, as shown in Fig. 1.3:

- The Art of Project Management: A Story about Work and Passion: This book gives you an overview of the OR-AS endeavors done in the past and the ideas that will be done in the future. It tells about the products and ideas of OR-AS and gives you a brief overview of the most important people who inspired us and the OR-AS products. It tells about work, and the passion that has led to the results of the hard work. It's not a scientific book. It isn't a managerial book either. It's just a story . . . about work and passion

P2 Engine

P2 Engine is a command line utility tool based on the LUA scripting language to generate gigabytes of project data. It generates project baseline scheduling data and risk analysis metrics as well as dynamic project progress data that can be used for

testing and validating novel research ideas. P2 Engine gives the user access to the complexity of various project analysis algorithms incorporated in ProTrack 3.0. The researcher can solve difficult and critical dynamic project scheduling optimization problems using ProTrack's intelligent algorithms. It can easily produce a enormous database of optimization results for a wide range of project management problems faster than ever before and advance the state-of-the-art knowledge available today. More information on P2 Engine can be found www.p2engine.com.

Research

All articles, books and the software tool ProTrack are the result of years of academic research. Most research done before and during the continuous development of ProTrack can be situated in the so-called Project Life Cycle (PLC, see Fig. 1.4). This cycle defines all phases between the start and end of the life of a project, and has been extensively described in various sources.

The aim of the research is threefold. First, the research goal is to search for determinants that influence the accuracy of earned value based predictive methods to forecast a project's final duration. A distinction is made between static determinants, which can be calculated before the start of the project (i.e. during the definition and scheduling phases, see study 1 of the Fig. 1.4) and dynamic determinants, which can be calculated during the project's execution and control phases (see study 2). Obviously, the ultimate goal is not the accuracy for the sake of accuracy, but rather to use this static and dynamic information to guide and improve the corrective action decision making process (see study 3). More information on the latest obtained research funding can be found at www.or-as.be or at the research site of the Operations Research and Scheduling group at www.projectmanagement.ugent.be.

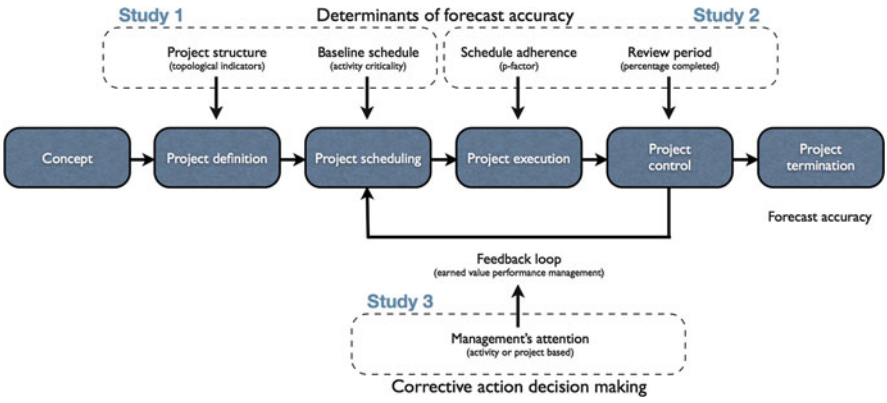

Fig. 1.4 The project life cycle and the three integrative studies used in all research studies

Part I
Baseline Scheduling

Chapter 2
Preface

BS1: An Introduction to Baseline Scheduling[1]

Baseline scheduling can be defined as the act of constructing a timetable to provide a start and end date for each project activity, taking activity relations, resource constraints and other project characteristics into account and aiming at reaching a certain scheduling objective.

The construction of a project baseline schedule is often a time-consuming and cumbersome task. However, the central role of the baseline schedule in a schedule risk analysis (see section "RA1: An Introduction to Risk Analysis" on page 109) and in the project control phase (see section "PC1: An Introduction to Project Control" on page 197) cannot be underestimated. It should indeed be generally accepted that the usability of a project baseline schedule is to act as a point of reference in the project life cycle, and hence, a project schedule should especially be considered as nothing more than a predictive model that can be used for resource efficiency calculations, time and cost risk analyses, project tracking and performance measurement, and so on.

The baseline scheduling topics of this book have been classified in the following categories:

- Network analysis
- Resource analysis
- Scheduling techniques

For an overview of the three dynamic scheduling dimensions, see Fig. 1.1 on page 2 or section "Welcome to PM Knowledge Center" on page 1. The different categories are briefly explained below.

[1]This section is also available as an article entitled "Dynamic scheduling: An introduction to baseline scheduling" published online at PM Knowledge Center.

M. Vanhoucke, *Integrated Project Management Sourcebook*,
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Network Analysis

Network analysis involves the construction of a project network containing activities and links between these activities to model the project network logic.

Resource Analysis

The presence of resources in project scheduling increases the complexity of finding an acceptable baseline schedule. Due to this inherent complexity, software scheduling tools are necessary to construct a resource feasible schedule without resource overallocations.

Scheduling Techniques

In order to have an idea about the underlying mechanism used by software tools, various scheduling techniques are discussed. These techniques are classified as follows:

- Critical path scheduling: Easy and straightforward scheduling techniques where it is assumed that no resource constraints are imposed.
- Resource scheduling: Complex scheduling techniques for projects where the use of renewable resources is restricted.
- Scheduling objectives: Information on the use of objectives that can be set during the construction of a project's baseline schedule.

Chapter 3
Network Analysis

BS2: Activity Networks[1]

A project network consists of a set of nodes and arcs. A project contains activities and precedence relations to model technological relations between pairs of activities. A project network can be represented in two formats, which is the topic of this article, as follows:

- Activity-on-the-node: Activities are represented by nodes and precedence relations by arcs.
- Activity-on-the-arc: Activities are represented by arcs and the precedence relations are implicitly embedded in the network nodes.

Activity-on-the-Node (AoN)

In an activity-on-the-node network format, project activities are represented by nodes and precedence relations by arcs between the nodes. Figure 3.1 displays a precedence relation between two activities in an activity-on-the-node format. It is said that activity 2 is a successor of activity 1 and activity 1 is a predecessor of activity 2.

This project network format is the default format in most commercial project management software tools such as MS Project, Primavera, ProTrack and many others. This format is easy to use in combination with different types of precedence relations (start-start, start-finish, finish-start and finish-finish relation, see article "*BS3: Precedence relations*" on page 16).

[1]This section is also available as an article entitled "Project networks: Nodes and arcs or arcs and nodes?" published online at PM Knowledge Center.

M. Vanhoucke, *Integrated Project Management Sourcebook*,
DOI 10.1007/978-3-319-27373-0_3

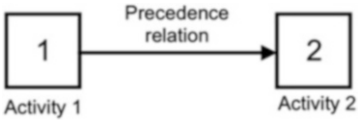

Fig. 3.1 An example activity link in activity-on-the-node format

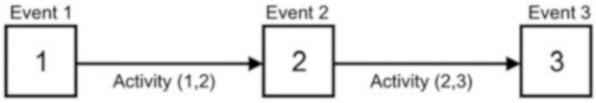

Fig. 3.2 An example activity link in activity-on-the-arc format

Table 3.1 A comparison between activity-on-the-node and activity-on-the-arc format

Activity-on-the-arc	Activity-on-the-node
Originally used for PERT and CPM	Used by most commercial software tools
Network representation is not unique due to dummy activities	Unique network representation (no dummy arcs)
Restricted to finish-start with zero time-lags	Can be easily extended to SS, SF, FS and FF relations with nonzero time-lags

Activity-on-the-Arc (AoA)

In an activity-on-the-arc network format, project activities are represented by arcs, as shown in Fig. 3.2. The nodes are events (or milestones) denoting the start and/or finish of a set of activities of the project and implicitly model the precedence relations between the nodes.

It is said that activity (2,3) is a successor of activity (1,2) and activity (1,2) is a predecessor of activity (2,3).

Unlike the activity-on-the-node format, the activity-on-the-arc network representation requires some rules to follow, which can be summarized in the following lines:

- Unique representation: Each activity can be a uniquely identified by its start and end node.
- Single start/end event: Each project network starts and ends with a single event (representing the start and end of the project).
- Dummy activities: Arcs to model extra precedence relations or to fulfill the two requirements written above.

Comparison

Table 3.1 displays a brief comparison between the two project network formats.

An illustrative example is given by the project data of Table 3.2 and the project networks in Fig. 3.3. While the AoA project networks are not unique due to the incorporation of one (top) or two (middle) dummy activities, the AoN network never contains dummy activities and is therefore always unique.

Table 3.2 Project data for an example project

Activity	Predecessors
A	None
B	A
C	A
D	B
E	B and C
F	D and E

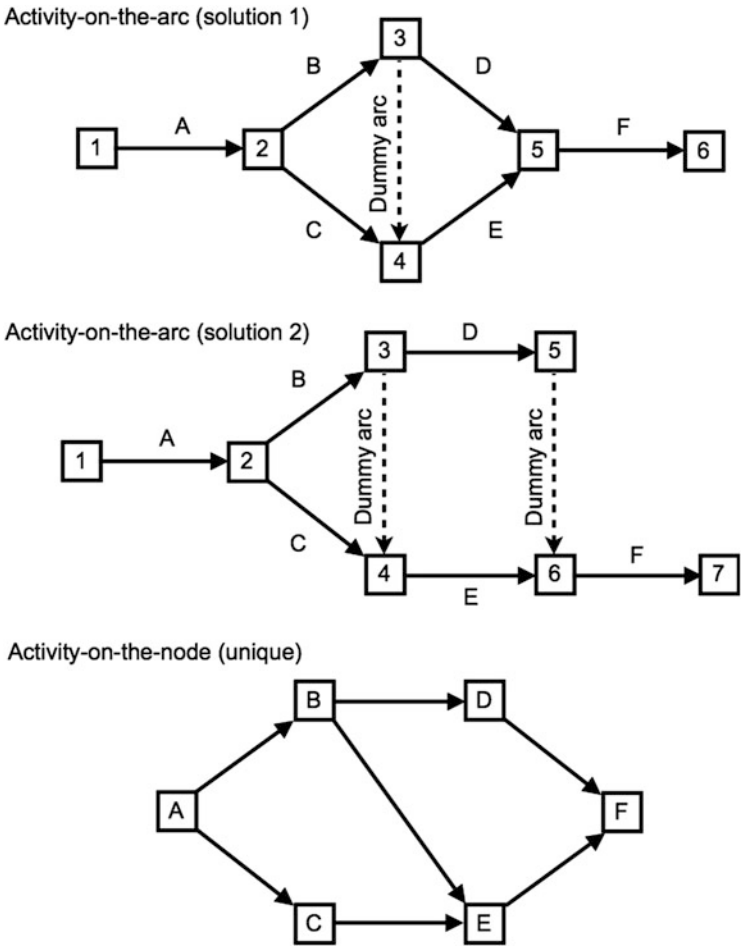

Fig. 3.3 An AoA (not unique) and AoN (unique) network for the project data of Table 3.2

Questions

1. The activity-on-the-arc representation is used as default format in most commercial project management software tools.

   (a) True
   (b) False

2. The activity-on-the-arc representation is restricted to finish-start relations with zero time-lags.

   (a) True
   (b) False

3. Dummy activities can be added to an activity-on-the-arc network in order to insert extra precedence relations to the network.

   (a) True
   (b) False

4. Assume the project data given in Table 3.3. The project data can be represented by one of the activity-on-the-node networks of Fig. 3.4 on page 15. Which one?

   (a) Network (a)
   (b) Network (b)
   (c) Network (c)
   (d) Network (d)

5. Based on the activity-on-the-arc project network of Fig. 3.5 on page 15, which of the following propositions is not correct? (The dashed lines indicate dummy arcs)

   (a) Activity G is a successor of activity C
   (b) Activity B can be scheduled in parallel with activity E
   (c) Activity G has no successors
   (d) Activity C can be scheduled in parallel with activity D

6. Both project networks in Fig. 3.6 on page 16 represent the same project.

   (a) True
   (b) False

Table 3.3 Example project data

Activity	Successors
A	B and C
B	D
C	E
D	F
E	B and F
F	None

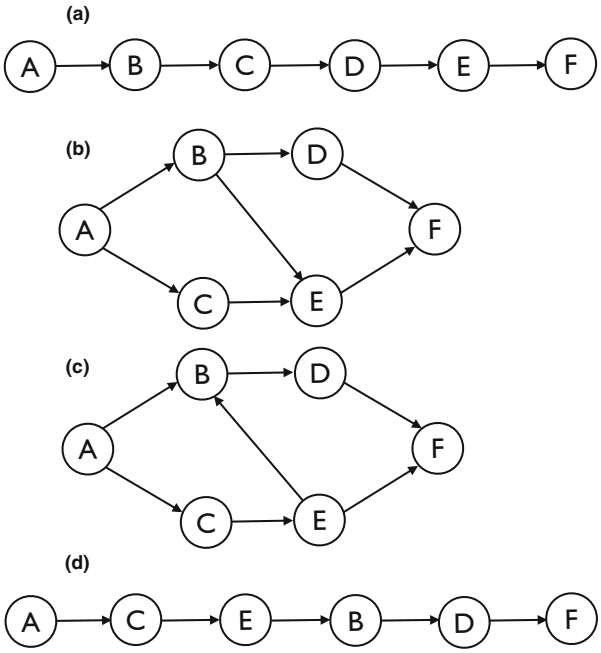

Fig. 3.4 Four example project networks

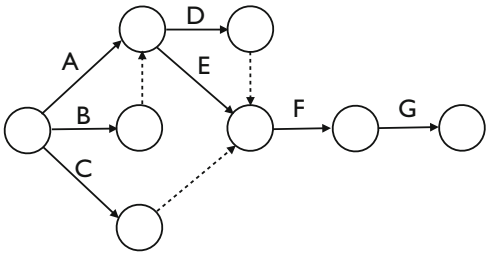

Fig. 3.5 Example project network

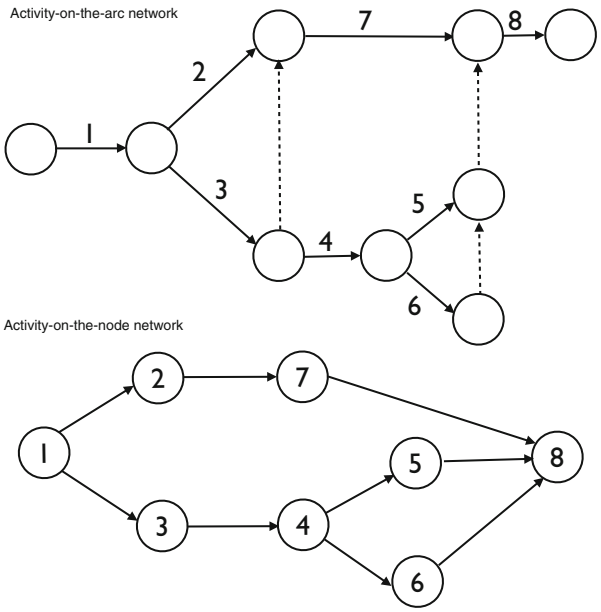

Fig. 3.6 Two example project networks

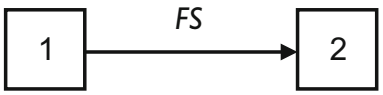

Fig. 3.7 An example activity link between activity 1 and 2

BS3: Precedence Relations[2]

A project network consists of a set of activities, represented as nodes in a network between which links are drawn to represent the technological precedence relations between these project activities. In Fig. 3.7, a finish-start precedence relation between activities 1 and 2 is used to imply that activity 2 cannot start earlier than the finish of activity 1.

[2]This section is also available as an article entitled "Activity links: How to add precedence relations between activities?" published online at PM Knowledge Center.

In general, three inputs are required from a project manager to define the precedence relations between activities, as given along the following lines:

- Time-lag of precedence relations: Zero or nonzero.
- Type of precedence relation: Finish-start, finish-finish, start-start and start-finish.
- Time-lag requirement of a precedence relation: Minimal or maximal.

Time-Lag

Each precedence relation has a time-lag to denote a minimal time-span between the two activities. Time-lags can be positive, zero or negative, as shown in Fig. 3.8.

A finish-start relation with a zero time-lag is used to imply that activity 2 can only start after the finish of activity 1. A zero time-lag implies that the second activity can start immediately after the finish of the first activity, or later. It does not force the immediate start after the finish of the first activity, but only describes the technological requirements and limitations that exist between two activities.

Similarly, a finish-start relation with a nonzero time-lag $n \neq 0$ can be used to imply that activity 2 can only start n time periods after the finish of activity 1, with n denoting a positive or negative number.

Types of Activity Link

While the default type of precedence relation between activities is a FS (finish-start) type, there are four different types of precedence relations between two activities, as graphically displayed in the figure below.

The four types of precedence relations of Fig. 3.9 can be summarized as follows:

- FS $= n$: Activity 2 can only start n time periods after the finish of activity 1.
- SS $= n$: Activity 2 can only start n time periods after the start of activity 1.
- FF $= n$: Activity 2 can only finish n time periods after the finish of activity 1.
- SF $= n$: Activity 2 can only finish n time periods after the start of activity 1.

with n the time-lag between activities 1 and 2.

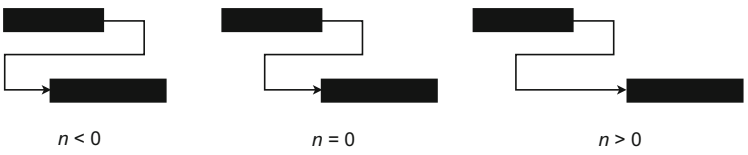

Fig. 3.8 Negative, zero and positive time-lags between two activities

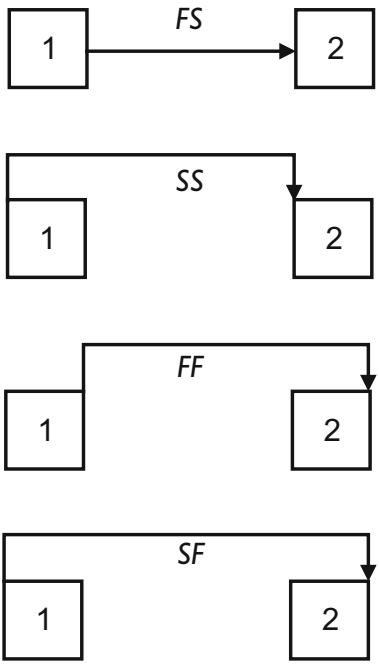

Fig. 3.9 Four types of precedence relations between activities 1 and 2

Minimal/Maximal

While it is assumed that precedence relations imply minimal requirements between two activities, they can be easily extended to maximal requirements. Although most commercial software tools do not incorporate the possibility of maximal time-lags, they are briefly discussed here.

- A finish-start relation with a minimal time-lag of n can be used to imply that activity 2 can only start n or more time periods after the finish of activity 1.
- A finish-start relation with a maximal time-lag of n can be used to imply that activity 2 can only start n or less time periods after the finish of activity 1.

Logically, the extension from a minimal to a maximal time-lag also holds for start-start, finish-finish and start-finish precedence relations. However, they often lead to an increased complexity of the project network. Minimal and maximal precedence relations can and often will be used in combination.

Questions

1. Assume a finish-start relation with a nonnegative time-lag between activities A and B. Activity B can start before the finish of activity A.

   (a) True
   (b) False

2. A start-finish relationship with a time-lag of T periods between activities A and B means that activity B can only start T periods after the finish of activity A.

   (a) True
   (b) False

3. A finish-start relation between activities A and B with a maximal time-lag of T periods means that activity B can only start T (or less) periods after the finish of activity A.

   (a) True
   (b) False

4. Assume a start-start relationship between activities A and B, with a maximal time-lag of 3. Activity A has a duration of 4 weeks and starts at the beginning of week 18, while activity B has a duration of 5 weeks. What is the latest possible finish time of activity B?

   (a) End of week 27.
   (b) End of week 21.
   (c) End of week 26.
   (d) End of week 25.

5. Assume a finish-start relation with a maximal time-lag of 3 between activity A and B and a start-start relation with a minimal time-lag of -3 between activity B and A. What is the earliest possible start time of activity A (duration $= 3$) if activity B (duration $= 2$) starts at time 15.

   (a) Week 9
   (b) Week 12
   (c) Week 15
   (d) Week 11

6. A finish-start relation with a minimal time-lag of 4 is the same as a finish-start relation with a maximal time-lag of -4.

   (a) True
   (b) False