

# Programming and Scheduling Techniques

Second Edition

**Thomas E. Uher** and  
**Adam S. Zantis**



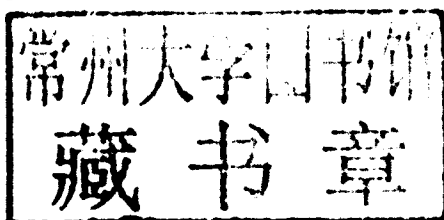
---

# Programming and Scheduling Techniques

---

Second Edition

Thomas E. Uher and  
Adam S. Zantis



**Spon Press**  
an imprint of Taylor & Francis  
LONDON AND NEW YORK

First edition published 2003  
by UNSW Press

This edition published 2011  
by Spon Press  
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

Simultaneously published in the USA and Canada  
by Spon Press  
711 Third Avenue, New York, NY 10017

*Spon Press is an imprint of the Taylor & Francis Group, an informa business*

© 2003, 2011 Thomas E. Uher and Adam S. Zantis

The right of Thomas E. Uher and Adam S. Zantis to be identified as authors of this work has been asserted by them in accordance with sections 77 and 78 of the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this book may be reprinted or reproduced or utilised in any form or by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying and recording, or in any information storage or retrieval system, without permission in writing from the publishers.

*Trademark notice:* Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

*British Library Cataloguing in Publication Data*

A catalogue record for this book is available from the British Library

*Library of Congress Cataloging in Publication Data*

Uher, Thomas E.

Planning and scheduling techniques / Thomas E. Uher and Adam S. Zantis.

p. cm.

Includes bibliographical references and index.

1. Project management. 2. Strategic planning. 3. Production scheduling. I. Zantis, Adam S. II. Title.

T56.8.U38 2011

658.4'04—dc22

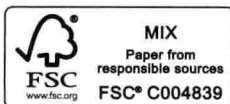
2010050588

ISBN: 978-0-415-60168-9 (hbk)

ISBN: 978-0-415-60169-6 (pbk)

ISBN: 978-0-203-83600-2 (ebk)

Typeset in Goudy  
by RefineCatch Limited, Bungay, Suffolk



Printed and bound in Great Britain by  
TJ International Ltd, Padstow, Cornwall

---

# Programming and Scheduling Techniques

---

Planning is an important management function and its effective execution is crucial to ensure the success of any project. This second edition of Thomas Uher's and Adam Zantis' textbook maintains its focus on operational rather than strategic aspects of programming and scheduling of projects, providing the reader with the practical planning skills needed to be successful.

Unlike most other textbooks that largely focus on the critical path method, *Programming and Scheduling Techniques* includes a comprehensive review of a range of practices used around the world. Topics covered in this thoroughly revised edition include:

- deterministic scheduling techniques including the bar chart, the critical path method, the critical chain method, the multiple activity chart and the line of balance
- a comparison of the critical path and critical chain scheduling techniques
- options for computer-based scheduling
- stochastic scheduling techniques including the critical path method based on Monte Carlo simulation and the Program Evaluation and Review Technique (PERT)
- risk in scheduling
- work study.

By covering a broad range of scheduling techniques this book is suitable for those planning projects in any industry, particularly in interdisciplinary or international contexts.

Learning activities, step-by-step guides, and a downloadable answers booklet make sure no reader is left behind. Written for students studying undergraduate and postgraduate architecture, building, construction/project management, quantity surveying, property development and civil engineering programs.

**Thomas E. Uher** was an Associate Professor in the Faculty of the Built Environment at the University of New South Wales between 1978 and 2009. He presently works as a consultant on project management, contract administration and partnering, and as an Adjudicator of payment claim disputes under the NSW, Queensland and Victorian Security of Payment Acts. He is author of over 100 journal articles and 3 books.

**Adam S. Zantis** has been working as a project planner and manager in the construction industry for the past seven years. Adam's expertise in planning and scheduling has been recognised by the University of New South Wales, where he currently lectures.

---

# Abbreviations

---

ACWP	Actual cost for work performed
AREA	Area/department
AS	Activity slack
BAC	Budget at completion
BCWP	Budget cost for work performed
BCWS	Budget cost for work schedule
CC	Critical chain
CCM	Critical chain management
CCS	Critical chain scheduling
CIM	Control interval and memory
CONS	Construction department
CONT	Contracts department
CPI	Cost performance index
CPM	Critical path method
CV	Cost variance
DEP	Department
EAC	Estimate at completion
EFD	Earliest finish date
EPS	Enterprise project structure
ES	Event slack
ESD	Earliest start date
ESTM	Estimating department
EV	Earned value
FF	Free float
FINC	Financial department
FTS	Finish-to-start
FTF	Finish-to-finish
HRMG	Human resource management department
ID	Identification code
ITEM	Item name
LSD	Latest start date
LFD	Latest finish date

LOB	Line of balance
LOCN	Location
LSM	Linear scheduling method
LSMh	Linear scheduling model
MAC	Multiple activity chart
MAX	Maximum
MBO	Management by objectives
MILE	Milestone
MIN	Minimum
OBS	Organisational breakdown structure
PC	Percentage complete
PERT	Program evaluation and review technique
PRCH	Purchasing department
RESP	Responsibility
RPM	Repetitive project modelling
RUF	Resource utilisation factor
SPI	Scheduled performance index
STS	Start-to-start
STF	Start-to-finish
SV	Scheduled variance
TF	Total float
TLS	Tender letting schedule
TOC	Theory of constraints
VPM	Vertical production method
WBS	Work breakdown structure

---

# Preface

---

Planning is the first functional step in any production process. It requires that every task essential in developing a construction project is identified, and carefully incorporated and integrated into an overall development programme that ensures successful project outcomes. Without an effective plan, there can be no control over the production process.

In any organisation, planning is essential at all management levels. Top managers are concerned with strategic and business planning, while middle and lower managers develop operational plans which formulate specific operational strategies for achieving the objectives set out in the strategic and business plans. This book addresses operational rather than strategic aspects of planning of construction projects. It describes specific scheduling techniques and processes commonly used in the construction industry. While used mainly at the construction stage, the described techniques and processes are suitable for application across all the stages of the project lifecycle.

Many books have been written on aspects of construction scheduling, but they largely focus on the critical path method and do not provide a comprehensive review of a range of scheduling techniques. This book attempts to redress this problem.

While this book serves as a reference for construction industry practitioners, it has mainly been written as a text and reference material for students studying architecture, building, construction management, civil engineering, and for quantity surveying undergraduate and postgraduate programmes.

The second edition of this book benefits from having Adam Zantis as second author. Adam has injected into this new edition his practical knowledge of applying various scheduling techniques in the construction industry. This is reflected in inclusion of status reporting in Chapter 6, *Project control*, the substantial revision of the material in Chapter 7, *Critical path scheduling by computer*, a revision of the material in Chapter 8, *Critical chain scheduling*, and inclusion of the new material on productivity rate databases in Chapter 11, *Work study*, and on risk contingency calculations in Chapter 12, *Risk and scheduling*.

The format of the book remains much the same with the previously discussed scheduling techniques retained. However, the content of some chapters has been

either revised or updated and, where appropriate, expanded. Scheduling techniques described in the book include the bar chart, critical path method, critical chain scheduling, multiple activity chart and line of balance. Although not strictly a scheduling technique, work study has nevertheless been retained since it assists planners and project managers in developing efficient production methods.

T. E. Uher  
A. S. Zantis



---

# Contents

---

<i>List of tables</i>	ix
<i>List of figures</i>	xi
<i>Abbreviations</i>	xv
<i>Preface</i>	xvii
<b>1 The concept of planning and control</b>	<b>1</b>
1.1 Introduction	1
1.2 Planning process	2
1.3 Types of planning activities	6
1.4 Planning tools and techniques	7
1.5 Planning of construction projects	8
1.6 Planning tasks at different stages of the project lifecycle	15
1.7 Examples of construction plans and schedules	20
1.8 Summary	27
<b>2 Bar charts</b>	<b>28</b>
2.1 Introduction	28
2.2 What is a bar chart?	28
2.3 Linked bar chart	30
2.4 Process of developing a bar chart	31
2.5 Activity duration	32
2.6 Risk contingency	32
2.7 Method statement	33
2.8 Summary	35
<b>3 The critical path method</b>	<b>36</b>
3.1 Introduction	36
3.2 The critical path method	36

3.3	<i>A brief history of the critical path method</i>	37
3.4	<i>The arrow method</i>	37
3.5	<i>The precedence method</i>	39
3.6	<i>The concept of link lag</i>	49
3.7	<i>Summary</i>	55
	<i>Exercises</i>	55
<b>4</b>	<b>Resource management</b>	<b>59</b>
4.1	<i>Introduction</i>	59
4.2	<i>Resources</i>	60
4.3	<i>Distribution of resources</i>	61
4.4	<i>Resource levelling</i>	63
4.5	<i>Resource levelling performed by computers</i>	71
4.6	<i>Managing the labour resource</i>	71
4.7	<i>Managing materials</i>	74
4.8	<i>Managing plant and equipment</i>	76
4.9	<i>Summary</i>	80
	<i>Exercises</i>	80
<b>5</b>	<b>Overlapping network models</b>	<b>86</b>
5.1	<i>Introduction</i>	86
5.2	<i>Finish-to-start link (FTS)</i>	87
5.3	<i>Start-to-start link (STS)</i>	88
5.4	<i>Finish-to-finish link (FTF)</i>	89
5.5	<i>Start-to-finish link (STF)</i>	91
5.6	<i>A compound link</i>	92
5.7	<i>Free and total float in overlapped networks</i>	94
5.8	<i>Calculating an overlapped critical path schedule</i>	96
5.9	<i>Overlapping of critical path schedules by computer</i>	102
5.10	<i>Redundant links in precedence schedules</i>	102
5.11	<i>Summary</i>	103
	<i>Exercises</i>	103
<b>6</b>	<b>Project control</b>	<b>106</b>
6.1	<i>Introduction</i>	106
6.2	<i>Project performance outcomes</i>	106
6.3	<i>Project control system</i>	107
6.4	<i>Monitoring performance</i>	108
6.5	<i>Evaluating performance</i>	110

6.6	<i>A schedule adjustments/updates</i>	112
6.7	<i>Cost–time optimisation</i>	115
6.8	<i>Earned value</i>	130
6.9	<i>Summary</i>	134
	<i>Exercises</i>	134
<b>7</b>	<b>Critical path scheduling by computer</b>	<b>139</b>
7.1	<i>Introduction</i>	139
7.2	<i>Brief overview of Primavera Project Planner P6 software</i>	140
7.3	<i>Scheduling a residential project using Primavera P6</i>	144
7.4	<i>Overlapping models in Primavera P6</i>	151
7.5	<i>BIM software</i>	154
7.6	<i>Summary</i>	157
<b>8</b>	<b>Critical chain scheduling</b>	<b>159</b>
8.1	<i>Introduction</i>	159
8.2	<i>Shortcomings of the critical path method</i>	159
8.3	<i>Theory of constraints</i>	161
8.4	<i>Critical chain scheduling</i>	162
8.5	<i>Comparison of critical path method (CPM) and critical chain scheduling (CCS)</i>	164
8.6	<i>Summary</i>	176
<b>9</b>	<b>Multiple activity charts</b>	<b>177</b>
9.1	<i>Introduction</i>	177
9.2	<i>Format of a MAC</i>	178
9.3	<i>Preparation of a MAC</i>	178
9.4	<i>Example of MAC scheduling</i>	180
9.5	<i>Summary</i>	188
	<i>Exercises</i>	188
<b>10</b>	<b>The line of balance technique</b>	<b>194</b>
10.1	<i>Introduction</i>	194
10.2	<i>Concept of LOB</i>	195
10.3	<i>Concept of delivery programme in LOB</i>	197
10.4	<i>Developing a LOB schedule</i>	199
10.5	<i>Developing a LOB schedule for projects requiring multiple crews</i>	203
10.6	<i>Summary</i>	207
	<i>Exercises</i>	208

<b>11 Work study</b>	<b>210</b>
11.1 Introduction	210
11.2 Method study	211
11.3 Work measurement	221
11.4 Activity duration	224
11.5 Evaluating the economic viability of alternative methods of work	228
11.6 Summary	237
Exercises	237
 <b>12 Risk and scheduling</b>	 <b>239</b>
12.1 Introduction	239
12.2 Risk and uncertainty	239
12.3 Principles of risk management	240
12.4 Risk management plan	252
12.5 Risk-time contingency calculation techniques	252
12.6 Probability scheduling	255
12.7 Summary	259
 <b>13 The Program Evaluation and Review Technique (PERT)</b>	 <b>260</b>
13.1 Introduction	260
13.2 Network construction	261
13.3 The probability concept in PERT	262
13.4 The PERT method modelled on the precedence method of CPM	265
13.5 Summary	269
Exercises	269
 References	 272
Index	275

---

# Tables

---

1.1	Specific activities of a site crane	21
1.2	Advantages and disadvantages of different presentation forms of plans and schedules	26
2.1	A method statement	34
3.1	Typical information required for construction of a precedence network	40
3.2	Data for a precedence schedule	55
3.3	Data for a precedence schedule	56
3.4	Data for a precedence schedule	56
3.5	Data for a precedence schedule	56
3.6	Data for a precedence schedule	57
4.1	Data for the resource-levelling example	66
4.2	Example of a purchasing schedule of materials	75
4.3	A delivery schedule of materials, week commencing 28 June 2010	76
4.4	The lifting demand information	78
4.5	Data for the precedence schedule	81
4.6	Data for the precedence schedule	82
4.7	Activities to be performed by a crane	83
6.1	The feedback data for the fitout project	114
6.2	Estimates of cost and time values for the activity 'Excavate'	119
6.3	Data for the compression example	122
6.4	Data for the compression example	135
6.5	Data for the compression example	136
6.6	Data for the compression example	137
6.7	Data for the earned value example	138
7.1	The project data	145
7.2	Normal and total resource limits	148
7.3	The project cost data	152
7.4	The cost rates for labour and plant	153
7.5	Data on progress of the project on day 27	153
7.6	A sample of a cost report for the project review on day 27	155

8.1	Case study data	165
8.2	Contingency in the CPM schedule	167
8.3	Float in the CPM schedule	167
8.4	Critical chain activity calculation with critical chain activities highlighted	170
8.5	Project buffer calculation	170
8.6	Feeding buffer #1 calculation	172
8.7	Feeding buffer #2 calculation	172
8.8	Feeding buffer #3 calculation	172
8.9	Contingency in the critical path	174
8.10	Float in the CC schedule	174
8.11	Total float and contingency case study data comparison	175
9.1	The work content summary sheet for the project in question	183
9.2	Data for the MAC example	189
9.3	Data for the MAC example	190
9.4	Data for the MAC example	191
9.5	Data for the MAC example	193
10.1	The LOB table of individual trade packages	201
10.2	The LOB table with buffer zones of six days	202
10.3	The volume of work per activity expressed in person-hours	204
10.4	Crew sizes and the rate of output	204
10.5	Number of crews, duration of activities, total duration, and start and finish dates	206
10.6	Start and finish dates adjusted for multiple crews	207
10.7	The final start and finish dates with buffer zones	207
11.1	Example 1 activities and the standard times of work	229
11.2	Example 1 costs of committed resources	229
11.3	Example 2 activities and their standard times of work	233
11.4	Example 2 costs of committed resources	233
11.5	Data for the work study example	238
12.1	The frequency of sales of computers	257
13.1	A comparison of interpretation of the arrow method of CPM and the PERT method	261
13.2	The probability table for a normal distribution	264
13.3	Three time estimates, $a$ , $m$ and $b$ , of activity durations and $t_e$ , $s$ and $s^2$ values	266
13.4	Data for the PERT example	269
13.5	Data for the PERT example	270
13.6	Data for the PERT example	271

---

# Figures

---

1.1	A typical production process	2
1.2	WBS of a project (from Hamilton 1997: 86)	10
1.3	Example of time and resource schedules	13
1.4	Cost of change and possible cost/time reduction across the project lifecycle	16
1.5	Example of a tender letting schedule	22
1.6	Example of a staging diagram	24
1.7	Example of a procurement schedule	25
2.1	A typical bar chart	29
2.2	A linked bar chart	30
2.3	A sequential bar chart	35
3.1	Graphic representation of activity in an arrow schedule	38
3.2	Example of a chain of activities in an arrow schedule	38
3.3	Labelling protocol	39
3.4	Linking of activities in a precedence schedule	40
3.5	Example of a precedence network	41
3.6	Labelling protocol	42
3.7	The calculated precedence schedule	45
3.8	The graphic definition of float in a precedence network	47
3.9	A link lag in the precedence network	51
3.10	Example of a precedence schedule	52
3.11	Example of a precedence network including lags and the critical path	53
4.1	Example of the uniform distribution of a resource	61
4.2	Example of the uneven distribution of a resource	62
4.3	Example of the normal and the right-skewed distributed resources	63
4.4	A complex distribution of resources	63
4.5	A precedence network for the resource-levelling example	65
4.6	A bar chart of the resource-levelling example	67
4.7	A histogram of the labour demand before and after levelling	67

4.8	Lowering the resource demand by varying the distribution of the resource	70
4.9	Lowering the resource demand by splitting and varying the distribution of the resource	70
4.10	Lowering the resource demand by extending the project duration	71
4.11	The linked bar chart with the total labour demand histogram	73
4.12	Example of a trend graph showing the cumulative planned and actual labour demand	74
4.13	Example of a demand histogram for cranes and hoists	77
4.14	Example of the crane and hoist lifting demand histograms	79
4.15	The precedence schedule	81
4.16	The precedence schedule	82
5.1	Example of the finish-to-start link	87
5.2	Example of the start-to-start link	88
5.3	Example of the finish-to-finish link	90
5.4	Example of a start-to-finish link	91
5.5	Example of a compound link	93
5.6	Example of an overlapped precedence schedule	95
5.7	The fully calculated overlapped precedence schedule	95
5.8	The adjusted overlapped precedence schedule	100
5.9	A linked bar chart of the overlapped precedence schedule	101
5.10	A redundant and a valid link in a precedence schedule	102
5.11	The precedence schedule	103
5.12	The precedence schedule	104
5.13	The precedence schedule	105
6.1	Example of a time-sheet	109
6.2	Example of the trend graph for cumulative formwork production	111
6.3	Histograms of the planned and actual demand of a crane	112
6.4	A precedence schedule of the fitout project prior to the progress review	113
6.5	A precedence schedule of the fitout project after update on week 7	115
6.6	Example of a weekly program report	116
6.7	An activity's cost–time relationship	117
6.8	Project cost components	119
6.9	The optimum cost–time point of the activity 'Excavate'	120
6.10	The project schedule before compression	122
6.11	The project schedule after the first compression	125
6.12	The project schedule after the second compression	126
6.13	The project schedule after the third compression	127
6.14	Assessment of project cost performance	130
6.15	Earned value elements (adapted from Burke (1999: 205))	131
6.16	The precedence schedule for the example	135
6.17	The precedence schedule for the example	136
6.18	The precedence schedule for the example	136



7.1	Hierarchical diagram showing EPS, OBS and WBS relationships	142
7.2	A WBS for a shopping centre development project	143
7.3	A manually produced and calculated precedence schedule of the residential project	146
7.4	The time schedule in the form of a linked bar chart	147
7.5	A resource histogram of the resource 'Carpenter' before levelling	148
7.6	The resource schedule in the form of a linked bar chart with a baseline	149
7.7	A resource histogram of 'Carpenter' after levelling	150
7.8	The project schedule in the form of a linked bar chart on day 27	154
7.9	An overlapped schedule of the project	156
7.10	An overlapped linked bar chart	157
8.1	CPM schedule	166
8.2	Schedule calculated with aggressive/optimistic activity durations	169
8.3	Part complete CC schedule with project buffer inserted	171
8.4	Complete CC schedule with buffers inserted	173
9.1	A floor plan of the case study project	181
9.2	A schedule of work for segments A and B	182
9.3	A schedule of work for segment C	182
9.4	A MAC schedule with the key activities	184
9.5	The completed MAC schedule	186
9.6	The precedence schedule for the example	189
9.7	The precedence schedule for the example	190
9.8	The footing plan	191
9.9	The floor plan	192
9.10	The precedence schedule	192
10.1	A LOB schedule of activities with identical cycle times	196
10.2	A LOB schedule of activities with different cycle times	196
10.3	The delivery rate graph	197
10.4	A construction schedule of one house with lead-times	198
10.5	The planned and actual production output graph	199
10.6	A precedence schedule of work related to one typical floor	200
10.7	The LOB schedule of the fitout project	203
10.8	A construction schedule of a house	204
10.9	The LOB schedule for the housing project	208
10.10	The precedence schedule for the example	209
10.11	The precedence schedule for the example	209
11.1	The definition of work study	212
11.2	Standard symbols used in process charts	214
11.3	Example of a process chart	214
11.4	Example of a flow process chart: the current method of work	216
11.5	Example of a flow process chart: the improved method of work	217
11.6	Example of a flow chart	218