

# Contents

<b>Preface to the Sixth Edition</b> .....	vii
<b>Supplementary Electronic Material</b> .....	xi
<b>1 Introduction</b> .....	1
1.1 The Role of Scheduling .....	1
1.2 The Scheduling Function in an Enterprise .....	4
1.3 Outline of the Book .....	6
<b>Part I Deterministic Models</b>	
<b>2 Deterministic Models: Preliminaries</b> .....	13
2.1 Framework and Notation .....	13
2.2 Examples .....	20
2.3 Classes of Schedules .....	21
2.4 Complexity Hierarchy .....	26
<b>3 Single Machine Models (Deterministic)</b> .....	35
3.1 The Total Weighted Completion Time .....	36
3.2 The Maximum Lateness .....	42
3.3 The Number of Tardy Jobs .....	47
3.4 The Total Tardiness—Dynamic Programming .....	51
3.5 The Total Tardiness—An Approximation Scheme .....	55
3.6 The Total Weighted Tardiness .....	58
3.7 Online Scheduling .....	61
3.8 Discussion .....	66
<b>4 Advanced Single Machine Models (Deterministic)</b> .....	73
4.1 The Total Earliness and Tardiness .....	74
4.2 Primary and Secondary Objectives .....	81
4.3 Multiple Objectives: A Parametric Analysis .....	83
4.4 The Makespan with Sequence Dependent Setup Times .....	86
4.5 Job Families with Setup Times .....	95

4.6	Batch Processing .....	102
4.7	Discussion .....	108
<b>5</b>	<b>Parallel Machine Models (Deterministic)</b> .....	<b>115</b>
5.1	The Makespan without Preemptions .....	116
5.2	The Makespan with Preemptions .....	126
5.3	The Total Completion Time without Preemptions .....	133
5.4	The Total Completion Time with Preemptions .....	137
5.5	Due Date Related Objectives .....	140
5.6	Online Scheduling .....	141
5.7	Discussion .....	145
<b>6</b>	<b>Flow Shops and Flexible Flow Shops (Deterministic)</b> .....	<b>153</b>
6.1	Flow Shops with Unlimited Intermediate Storage .....	154
6.2	Flow Shops with Limited Intermediate Storage .....	164
6.3	Proportionate Flow Shops with Unlimited and Limited Intermediate Storage .....	170
6.4	Proportionate Flow Shops with Reentry .....	176
6.5	Flexible Flow Shops with Unlimited Intermediate Storage .....	179
6.6	Discussion .....	181
<b>7</b>	<b>Job Shops (Deterministic)</b> .....	<b>187</b>
7.1	Disjunctive Programming and Branch and Bound .....	188
7.2	The Shifting Bottleneck Heuristic and the Makespan .....	197
7.3	The Shifting Bottleneck Heuristic and the Total Weighted Tardiness .....	205
7.4	Constraint Programming and the Makespan .....	211
7.5	Discussion .....	219
<b>8</b>	<b>Open Shops (Deterministic)</b> .....	<b>225</b>
8.1	The Makespan without Preemptions .....	225
8.2	The Makespan with Preemptions .....	229
8.3	The Maximum Lateness without Preemptions .....	232
8.4	The Maximum Lateness with Preemptions .....	237
8.5	The Number of Tardy Jobs .....	241
8.6	Discussion .....	242

## Part II Stochastic Models

<b>9</b>	<b>Stochastic Models: Preliminaries</b> .....	<b>251</b>
9.1	Framework and Notation .....	251
9.2	Distributions and Classes of Distributions .....	252
9.3	Stochastic Dominance .....	256
9.4	Impact of Randomness on Fixed Schedules .....	259
9.5	Classes of Policies .....	263

<b>10</b>	<b>Single Machine Models (Stochastic)</b>	271
10.1	Arbitrary Distributions without Preemptions	271
10.2	Arbitrary Distributions with Preemptions: the Gittins Index	278
10.3	Likelihood Ratio Ordered Distributions	283
10.4	Exponential Distributions	286
10.5	Discussion	293
<b>11</b>	<b>Single Machine Models with Release Dates (Stochastic)</b>	299
11.1	Arbitrary Release Dates and Arbitrary Processing Times without Preemptions	300
11.2	Priority Queues, Work Conservation, and Poisson Releases	302
11.3	Arbitrary Releases and Exponential Processing Times with Preemptions	306
11.4	Poisson Releases and Arbitrary Processing Times without Preemptions	312
11.5	Discussion	318
<b>12</b>	<b>Parallel Machine Models (Stochastic)</b>	325
12.1	The Makespan and Total Completion Time without Preemptions	326
12.2	The Makespan and Total Completion Time with Preemptions	335
12.3	Due Date Related Objectives	345
12.4	Bounds Obtained through Online Scheduling	348
12.5	Discussion	350
<b>13</b>	<b>Flow Shops, Job Shops, and Open Shops (Stochastic)</b>	357
13.1	Stochastic Flow Shops with Unlimited Intermediate Storage	358
13.2	Stochastic Flow Shops with Blocking	364
13.3	Stochastic Job Shops	369
13.4	Stochastic Open Shops	370
13.5	Discussion	376
<hr/>		
<b>Part III Scheduling in Practice</b>		
<b>14</b>	<b>General Purpose Procedures for Deterministic Scheduling</b>	383
14.1	Dispatching Rules	384
14.2	Composite Dispatching Rules	385
14.3	Local Search: Simulated Annealing and Tabu-Search	390
14.4	Local Search: Genetic Algorithms	397
14.5	Ant Colony Optimization	399
14.6	Discussion	401
<b>15</b>	<b>More Advanced General Purpose Procedures</b>	407
15.1	Beam Search	408
15.2	Decomposition Methods and Rolling Horizon Procedures	410
15.3	Constraint Programming	415

15.4	Market-Based and Agent-Based Procedures .....	419
15.5	Procedures for Scheduling Problems with Multiple Objectives .....	426
15.6	Discussion .....	432
<b>16</b>	<b>Modeling and Solving Scheduling Problems in Practice .....</b>	<b>439</b>
16.1	Scheduling Problems in Practice .....	440
16.2	Cyclic Scheduling of a Flow Line .....	443
16.3	Scheduling of a Flexible Flow Line with Limited Buffers and Bypass .....	448
16.4	Scheduling of a Flexible Flow Line with Unlimited Buffers and Setups .....	453
16.5	Scheduling a Bank of Parallel Machines with Jobs having Release Dates and Due Dates .....	460
16.6	Discussion .....	462
<b>17</b>	<b>Design and Implementation of Scheduling Systems: Basic Concepts .....</b>	<b>467</b>
17.1	Systems Architecture .....	468
17.2	Databases, Object Bases, and Knowledge-Bases .....	470
17.3	Modules for Generating Schedules .....	475
17.4	User Interfaces and Interactive Optimization .....	478
17.5	Generic Systems vs. Application-Specific Systems .....	484
17.6	Implementation and Maintenance Issues .....	487
<b>18</b>	<b>Design and Implementation of Scheduling Systems: More Advanced Concepts .....</b>	<b>493</b>
18.1	Robustness and Reactive Decision Making .....	494
18.2	Machine Learning Mechanisms .....	499
18.3	Design of Scheduling Engines and Algorithm Libraries .....	504
18.4	Reconfigurable Systems .....	508
18.5	Web-Based Scheduling Systems .....	510
18.6	Discussion .....	513
<b>19</b>	<b>Examples of System Designs and Implementations .....</b>	<b>519</b>
19.1	SAP's Production Planning and Detailed Scheduling .....	520
19.2	IBM's Independent Agents Architecture .....	524
19.3	AMD's Real Time Dispatching and Agent Scheduling .....	527
19.4	ASPROVA Advanced Planning and Scheduling .....	533
19.5	SIEMENS Opcenter APS .....	537
19.6	DELMIA Ortens Production Scheduler .....	542
19.7	CYBERPLAN - A System Developed by Cybertec .....	546
19.8	LEKIN - A System Developed in Academia .....	551
19.9	Discussion .....	558

<b>20 What Lies Ahead?</b> .....	559
20.1 Theoretical Research .....	559
20.2 Applied Research .....	563
20.3 Systems Development .....	566
<b>Appendices</b> .....	571
<b>A Mathematical Programming: Formulations and Applications</b> .....	573
A.1 Linear Programming Formulations .....	573
A.2 Integer Programming Formulations .....	577
A.3 Bounds, Approximations, and Heuristics Based on Linear Programming .....	581
A.4 Disjunctive Programming Formulations .....	583
<b>B Deterministic and Stochastic Dynamic Programming</b> .....	587
B.1 Deterministic Dynamic Programming .....	587
B.2 Stochastic Dynamic Programming .....	591
<b>C Constraint Programming</b> .....	595
C.1 Constraint Satisfaction .....	595
C.2 Constraint Programming .....	597
C.3 An Example of a Constraint Programming Language .....	599
C.4 Constraint Programming vs. Mathematical Programming .....	600
<b>D Complexity Theory</b> .....	603
D.1 Preliminaries .....	603
D.2 Polynomial Time Solutions versus NP-Hardness .....	606
D.3 Examples .....	609
D.4 Fixed Parameter Tractability .....	612
D.5 Approximation Algorithms and Schemes .....	615
<b>E Complexity Classification of Deterministic Scheduling     Problems</b> .....	621
<b>F Overview of Stochastic Scheduling Problems</b> .....	627
<b>G Selected Scheduling Systems</b> .....	633
<b>H The Legin System</b> .....	637
H.1 Formatting of Input and Output Files .....	637
H.2 Linking Scheduling Programs .....	639
<b>References</b> .....	645
<b>Subject Index</b> .....	685
<b>Name Index</b> .....	691