

Manufacturing Scheduling Systems

Jose M. Framinan · Rainer Leisten
Rubén Ruiz García

Manufacturing Scheduling Systems

An Integrated View on Models, Methods
and Tools

 Springer

Jose M. Framinan
Departamento de Organización
Industrial y Gestión de Empresas
Universidad de Sevilla Escuela
Superior de Ingenieros
Isla de la Cartuja
Seville
Spain

Rubén Ruiz García
Grupo de Sistemas de Optimización
Aplicada, Instituto Tecnológico
de Informática
Universitat Politècnica de València
Valencia
Spain

Rainer Leisten
Fakultät für Ingenieurwissenschaften
Allgemeine Betriebswirtschaftslehre und
Operations Management
Universität Duisburg-Essen
Duisburg
Germany

ISBN 978-1-4471-6271-1 ISBN 978-1-4471-6272-8 (eBook)
DOI 10.1007/978-1-4471-6272-8
Springer London Heidelberg New York Dordrecht

Library of Congress Control Number: 2013956332

© Springer-Verlag London 2014

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

To Carmen, Julio, and Daniel

Jose M. Framinan

To Karin, Steven, and Annemarie

Rainer Leisten

To Gema and Diego

Rubén Ruiz García

Preface

Obtaining economic and reliable schedules constitutes the core of excellence in customer service and of efficiency in manufacturing operations. While few areas have been more productive in decision sciences than scheduling, only a fraction of the vast amount of scheduling research has been translated into practice. On one hand, the inherent complexity of most scheduling problems has led to an excessively fragmented and specialised field in which different facets and issues are treated in an independent manner as goals themselves, lacking a unifying view of the scheduling problem. Aside, scientific brilliance and mathematical elegance has been sometimes prevalent to practical, hands-on approaches, producing specific procedures of narrow application. Finally, the nearly non-existence of research on implementation issues in scheduling as well as the scarcity of case studies has not helped in translating valuable research findings into industry.

In this book we attempt to overcome these limitations by presenting an integrated framework for formulating, developing and implementing systems that can be effectively used for supporting manufacturing scheduling decisions. To do so, we have intentionally avoided the traditional taxonomy style of many scheduling approaches and focused on the explanation and integration of the different issues into a (hopefully) coherent framework for modeling, solving and implementing scheduling decisions. Therefore, the book does not contain a detailed description of specific models and/or procedures, but rather will present a general overview of the scheduling field in order to provide the tools to conduct an up-to-date scheduling research and practice. To compensate this, we include a generous compilation and discussion of related literature for further reading, so the reader can easily track the main contributions of particular interest.

The book is intended for an ample audience who wish to get an overview of actual scheduling topics. It may constitute a starting point for researchers in the scheduling field. Also, post-graduate students with a focus on operations management can be attracted by the content of the book. Practitioners in the field would feel comfortable with many of the models and systems presented in the book as well, as they can easily see in them real-life cases. As a result, the book is not intended to be read sequentially, but is designed to support different itineraries, providing comprehensive introductory chapters/sections before detailed explanation of specific topics.

There are few but important prerequisites for this book. Knowledge of the most basic concepts of production management is required, although an effort is done in [Chap. 2](#) to place scheduling into context. Maths will appear profusely in some parts of the book, mostly in the chapters devoted to scheduling models.

Organisation of the book

The book is structured into five parts. In the first part, we introduce the main definitions and notation, and present the framework that we will use throughout the book. In this framework, a scheduling system is defined as a collection of models (representations of scheduling problems), methods (procedures to obtain efficient solutions out of scheduling models), and tools (software devices to embed models and procedures in order to support the scheduling decision problem), together with the human elements operating the system. Models, procedures, and tools will constitute the next three parts of the book. A final part on scheduling systems is devoted to assemble all these elements together in a roadmap to guide the development of a scheduling system. The structure of the book is summarised in [Fig. 1](#).

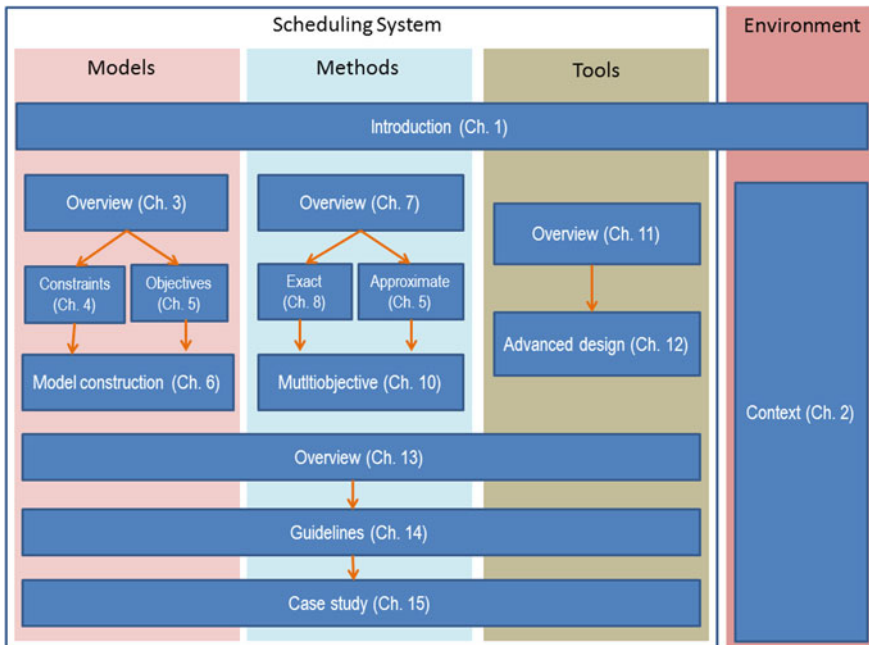


Fig. 1 Structure of the book

As mentioned before, the book does not have to be read comprehensively and sequentially. Manufacturing scheduling constitutes a topic of interest for different professional (including managers and top/intermediate staff in charge of operations management) and academic profiles (including production/manufacturing engineers, computer scientists, and different bachelors in operations research and management science). When used as a textbook, the instructors would have a clear idea about the content, sequence, and depth in which the different topics contained in the book should be learnt. Therefore, the subsequent lines are mainly intended as a rough advice whenever such supervision is not present.

We believe that a rather basic knowledge of the scheduling field can be gained by reading the introductory chapters of each part, i.e. [Chaps. 1, 3, 7, 11, and 13](#). A more classical (although, in our opinion, also more theoretical) itinerary for the scheduling field would exclude [Chap. 11](#) to [Chap. 15](#), and would stress issues related to modeling and solution procedures. Modeling would be reinforced by adding [Chaps. 4, 5, and 6](#). These three chapters are heavily interdependent and therefore should be read together, although readers with some scheduling background may skip some parts of [Chaps. 4 and 5](#), and focus instead on the discussions in [Chap. 6](#). A rather comprehensive understanding of solution procedures is provided in [Chaps. 8 and 9](#), whereas multiobjective scheduling issues are treated in [Chap. 10](#). Since multiobjective scheduling is a hot topic with practical and theoretical interest, we would favor its inclusion even at a basic level course. Nevertheless, most of it could be skipped if the reader adopts a more classical/basic view of the topic.

We think that [Chaps. 11 and 12](#) would be of particular value for an audience interested in the design and implementation of scheduling tools. [Chapter 11](#) would serve to grasp a general view on the topic, whereas [Chap. 12](#) is intended for readers with some background and experience on business information systems, and –in our opinion– should be spared for basic scheduling courses, unless they are heavily geared toward information systems/computer science.

We hope that users and consultants of manufacturing scheduling systems would find interesting [Chaps. 13 to 14](#), as the practical issues treated there are not usually subject of classical scheduling books. Despite the verbosity and apparent simplicity of some of the ideas contained in these chapters, they are mainly intended for an experienced reader who may better grasp the inherent complexity of the deployment of manufacturing scheduling systems and their integration with the human schedulers. We are not sure that many of the ideas contained there could be fully appreciated at a more basic level, although we think that at least a glimpse of those in [Chap. 13](#) should be given in order to avoid an excessively technical approach to the field, which in our opinion is and has been a rather common flaw in scheduling teaching and research.

Finally, [Chap. 15](#) may be used in many different itineraries, ranging from a basic level in which modeling and solution procedures issues are seen into

practice, to a more advanced discussion case in which success factors, shortcomings, lost opportunities, and learnt lessons can be debated.

Acknowledgements

In the process of writing this book, we are indebted to many people. The authors benefited from the careful reading of earlier versions of the book done by Manu Dios, Paz Perez-Gonzalez and Natalia Prischepov. The authors are also indebted to the many members and colleagues of their institutions at Seville, Duisburg, and Valencia. The collaborations, help and working atmosphere have proven to be key when writing this book. They also had to endure many of our absences when writing “the book” and we are really thankful for their support and patience.

January 2014

Jose M. Framinan
Rainer Leisten
Rubén Ruiz García

Contents

Part I Introduction to Manufacturing Scheduling

1	Overview of Manufacturing Scheduling	3
1.1	Introduction	3
1.2	Manufacturing Scheduling into Context.	4
1.3	Features of Scheduling	7
1.4	A Framework for Manufacturing Scheduling System	8
1.5	Basic Concepts.	9
1.5.1	Representation of Schedules	13
1.5.2	Classes of Schedules.	14
1.5.3	Combinatorial Nature of Manufacturing Scheduling.	15
1.6	Conclusions and Further Readings	16
	References	17
2	The Context of Manufacturing Scheduling	19
2.1	Introduction	19
2.2	A Framework of Manufacturing Scheduling.	19
2.3	The Closed View of Scheduling Problems and Decisions	20
2.3.1	Time.	21
2.3.2	Complexity	26
2.3.3	Variability	28
2.3.4	Flexibility	30
2.4	The Open View of Scheduling Problems and Decisions	31
2.4.1	Manufacturing Scheduling Within Production Management	32
2.4.2	Interfaces of Manufacturing Scheduling with Other Decisions in Production Management	39
2.4.3	Manufacturing Scheduling and Intra- and Inter-Organisational Supply Networks.	39
2.5	Conclusions and Further Readings	40
	References	41

Part II Scheduling Models

- 3 Overview of Scheduling Models 45**
 - 3.1 Introduction 45
 - 3.1.1 Modelling as an Approach to Scheduling Problem Solving. 45
 - 3.1.2 Types of Models and Common Errors in Modelling 47
 - 3.2 Formal Definitions 48
 - 3.2.1 Scheduling Model. 48
 - 3.2.2 Jobs and Machines 49
 - 3.2.3 Processing Layouts 51
 - 3.2.4 Additional Processing Constraints. 63
 - 3.2.5 Scheduling Criteria 65
 - 3.3 Classification of Scheduling Models 66
 - 3.3.1 Early Classification Schemes 66
 - 3.3.2 Current Classification Schemes 67
 - 3.4 Production Planning, Lot Sizing and Lot Streaming 69
 - 3.5 Conclusions and Further Readings 71
 - References 72

- 4 Scheduling Constraints 75**
 - 4.1 Introduction 75
 - 4.2 Process Constraints 76
 - 4.2.1 Job or Task Precedence Constraints 76
 - 4.2.2 Changeovers or Setup Times 78
 - 4.2.3 Machine Eligibility 81
 - 4.2.4 Permutation Sequences 82
 - 4.2.5 Machine Availability and Breakdowns 82
 - 4.2.6 Re-circulation, Re-processing and Skipping. 83
 - 4.2.7 No-Idle Machines 84
 - 4.2.8 Batching Machines 84
 - 4.3 Operations Constraints 85
 - 4.3.1 Interruption, Preemption and Splitting. 86
 - 4.3.2 Release Dates, Due Dates, Deadlines, Processing Windows. 87
 - 4.3.3 No Wait, Minimum and Maximum Time Lags and Overlapping. 87
 - 4.3.4 Special Processing Times 89
 - 4.4 Transportation Constraints 91
 - 4.5 Storage Constraints 92
 - 4.6 Other Constraints 93
 - 4.7 Conclusions and Further Readings 94
 - References 96

- 5 Objectives** 101
 - 5.1 Introduction 101
 - 5.2 A Rationale for Scheduling Objectives 102
 - 5.3 Performance Measures 104
 - 5.4 Scheduling Objectives 109
 - 5.4.1 Non Due Date Related Objectives 110
 - 5.4.2 Due Date Related Objectives 111
 - 5.4.3 Rescheduling-Related Objectives 116
 - 5.4.4 Additional Objectives 116
 - 5.5 Adding Weights, Priorities or Importance 119
 - 5.6 An Illustrative Example. 119
 - 5.7 Dealing with Conflicting Criteria: Multiobjective Scheduling. 122
 - 5.8 Conclusions and Further Readings 123
 - References 124

- 6 Construction of Scheduling Models** 127
 - 6.1 Introduction 127
 - 6.2 Basic Approaches to Construction of Scheduling Models 127
 - 6.2.1 Variables, Constraints and Objectives 129
 - 6.2.2 Some Basic Modelling Techniques Used in Manufacturing Scheduling 133
 - 6.3 Complexity Reduction in Manufacturing Scheduling Using Decomposition and Re-integration. 139
 - 6.4 Aggregation and Disaggregation. 142
 - 6.5 Validation and Verification of Modelling Approaches/Models. 146
 - 6.6 Conclusions and Further Readings 147
 - References 148

Part III Scheduling Methods

- 7 Overview of Scheduling Methods** 153
 - 7.1 Introduction 153
 - 7.2 Basic Concepts. 154
 - 7.2.1 Formal Definitions 154
 - 7.2.2 Assumptions 154
 - 7.3 Computational Complexity of Scheduling 156
 - 7.3.1 An Example. 157
 - 7.3.2 Algorithm Complexity 160
 - 7.3.3 Model Complexity 162
 - 7.3.4 Handling Computational Complexity 164

7.4	Scheduling Policies	166
7.4.1	Basic Dispatching Rules	167
7.4.2	Advanced Dispatching Rules	170
7.4.3	Combination of Dispatching Rules	172
7.5	Scheduling Algorithms	173
7.5.1	Exact Algorithms	174
7.5.2	Approximate Algorithms	175
7.6	Assessing Scheduling Methods	179
7.6.1	Real-World Adequacy	179
7.6.2	Formal Adequacy	180
7.7	Conclusions and Further Readings	188
	References	189
8	Exact Algorithms	191
8.1	Introduction	191
8.2	Exact Constructive Algorithms	192
8.2.1	Johnson's Algorithm	192
8.2.2	Lawler's Algorithm	194
8.2.3	Moore's Algorithm	194
8.3	Enumerative Algorithms	195
8.3.1	Integer Programming (IP)	195
8.3.2	Problem-Oriented B&B Approaches	204
8.3.3	Dynamic Programming	210
8.4	Conclusions and Further Readings	214
	References	215
9	Approximate Algorithms	217
9.1	Introduction	217
9.2	Two Sample Heuristics	218
9.2.1	The NEH Heuristic	218
9.2.2	The Shifting Bottleneck Heuristic	220
9.3	Some Ideas Behind Heuristics for Manufacturing Scheduling	230
9.3.1	Exclusion of Specific Operations	232
9.3.2	Modification/Aggregation of (Specific) Operations	233
9.3.3	Exclusion of Relations Between Operations	235
9.3.4	Modification of Time Scale or Adjustment Policy	235
9.3.5	Identification of Symmetry Properties	235
9.3.6	Combination of Enumeration and Construction of Solutions	236
9.3.7	Generation of Variants of Efficient Heuristics	237
9.3.8	Vector Modification	238
9.3.9	Modification Approaches Based on Real-World Features	239

- 9.4 Metaheuristics 240
 - 9.4.1 Main Concepts 241
 - 9.4.2 Simple Descent Search Methods. 246
 - 9.4.3 Simulated Annealing. 247
 - 9.4.4 Tabu Search. 248
 - 9.4.5 Genetic Algorithms. 249
 - 9.4.6 Other Metaheuristics 252
- 9.5 Other Techniques 253
 - 9.5.1 Lagrangean Relaxation 253
 - 9.5.2 Combination of Exact Approaches
with (Meta-) Heuristics 254
- 9.6 Conclusions and Further Readings 256
- References 257

- 10 Multi-Objective Scheduling. 261**
 - 10.1 Introduction 261
 - 10.2 Multi-Objective Nature of Many Scheduling Problems 262
 - 10.3 Definitions and Notation 263
 - 10.4 Multi-Objective Models. 266
 - 10.4.1 Weighted Combination of Objectives 267
 - 10.4.2 Lexicographical Optimisation. 267
 - 10.4.3 ϵ -Constraint Optimisation 268
 - 10.4.4 Goal Programming 269
 - 10.5 Multi-Objective Methods. 270
 - 10.5.1 Approaches to Multi-Objective Models. 271
 - 10.5.2 Algorithms for Multi-Criteria Scheduling Models. 273
 - 10.6 Comparison of Pareto Optimisation Algorithms 278
 - 10.6.1 Performance Measures 280
 - 10.6.2 Dominance Ranking 282
 - 10.6.3 Empirical Attainment Functions 282
 - 10.7 Scheduling Interfering Jobs 284
 - 10.8 Conclusions and Further Readings 285
 - References 287

Part IV Scheduling Tools

- 11 Overview of Scheduling Tools 291**
 - 11.1 Introduction 291
 - 11.2 Scheduling Tools 291
 - 11.3 Review of Scheduling Tools 293
 - 11.4 A Business Information Systems Approach
to Scheduling Tools 295
 - 11.5 Early Design of Architecture of Scheduling Tools 298

- 11.6 Requirements of a Scheduling Tool 300
 - 11.6.1 Scope of the System 300
 - 11.6.2 Modelling Requirements 302
 - 11.6.3 Problem-Solving Functionalities 303
 - 11.6.4 Solution-Evaluation Functionalities 306
 - 11.6.5 Rescheduling Functionalities 307
 - 11.6.6 Capacity Analysis Functionalities 308
 - 11.6.7 User Interface 309
 - 11.6.8 Integration with Existing Information Systems 310
 - 11.6.9 Summary of Revised Functionalities 311
- 11.7 An Integrated Modular Architecture
for Scheduling Systems 311
- 11.8 Conclusions and Further Readings 314
- References 315

- 12 Advanced Design of Scheduling Tools 319**
 - 12.1 Introduction 319
 - 12.2 Business Logic Unit/Data Abstraction Module 319
 - 12.3 Database Management Module 320
 - 12.4 User Interface Module 321
 - 12.4.1 Output Representation 323
 - 12.4.2 Scenario Management 327
 - 12.4.3 System Maintenance 328
 - 12.4.4 Scheduling Control 329
 - 12.4.5 Algorithm Generator Interface 329
 - 12.5 Schedule Generator Module 330
 - 12.6 Conclusions and Further Readings 332
 - References 333

Part V Scheduling Systems

- 13 Overview of Scheduling Systems 337**
 - 13.1 Introduction 337
 - 13.2 The Integration of Models, Methods and Tools 337
 - 13.3 The Organisational Perspective in Scheduling 338
 - 13.4 The Human Scheduler 340
 - 13.5 The Scheduling Process 340
 - 13.6 Features of Human Scheduling 343
 - 13.7 Integrating the Human Piece into the Scheduling System 345
 - 13.7.1 Humans on Command 345
 - 13.7.2 Acquiring Knowledge from Schedulers 345
 - 13.7.3 Training and Evaluation 346
 - 13.7.4 Smoothing the Environment 348

- 13.8 Conclusions and Further Readings 350
- References 351

- 14 Guidelines for Developing Scheduling Systems. 353**
 - 14.1 Introduction 353
 - 14.2 Manufacturing Scheduling Systems at Work 353
 - 14.3 General Hints. 355
 - 14.3.1 Incremental Deployment of the Scheduling System. . . 355
 - 14.3.2 A-B-C Analysis 355
 - 14.3.3 Avoid Technology-Dominant Approaches 356
 - 14.3.4 Modular Design and Implementation 357
 - 14.4 Layout Modeling 358
 - 14.4.1 Dynamic Nature of the Business 358
 - 14.4.2 Preprocessing/What-If Analysis 358
 - 14.5 Data 359
 - 14.5.1 Development of a Database Interface 359
 - 14.5.2 Data Quality 360
 - 14.5.3 Data Abstraction. 360
 - 14.5.4 Maintenance of Data. 360
 - 14.5.5 Keeping Interfaces Simple. 360
 - 14.5.6 Performance. 360
 - 14.6 Objectives 361
 - 14.6.1 Prioritisation of Objectives 361
 - 14.6.2 Taking Out Non-Conflicting Objectives 361
 - 14.6.3 Postpone the Selection of Objectives 362
 - 14.6.4 Transforming Objectives into Constraints 362
 - 14.7 Solution Procedures 363
 - 14.7.1 Focus on Feasibility 363
 - 14.7.2 Take into Account the Available Decision Time 363
 - 14.7.3 Providing a Set of Alternative Solutions 364
 - 14.7.4 Transparency of Solution Procedures 364
 - 14.7.5 Design of Algorithms 365
 - 14.7.6 Manipulation of Solutions 366
 - 14.7.7 Using Already Available Technology 366
 - 14.8 Constraints. 367
 - 14.9 Conclusions and Further Readings 367
 - References 368

- 15 A Case Study: Ceramic Tile Production 371**
 - 15.1 Introduction 371
 - 15.2 The Production Process of Ceramic Tiles 372
 - 15.3 Modeling the Ceramic Tile Production Process 375
 - 15.3.1 Initial Model 375
 - 15.3.2 A More Detailed Model 377

- 15.4 Development and Deployment of the Scheduling System 385
 - 15.4.1 Gathering Initial Data for CTPP_Model_1 385
 - 15.4.2 Gathering Additional Data for CTPP_Model_2 389
 - 15.4.3 Storage, Retrieval and Maintenance of the Data 390
 - 15.4.4 Final Implementation and Results 391
- References 394
- Index 397**