Chemical Production Scheduling

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Mixed-Integer Programming Models and Methods

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To the memory of my father.

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Preface

Background and Motivation

Scheduling is a decision-making process that concerns the allocation of limited resources to competing tasks over time with the goal of optimizing one or more objectives. Scheduling appears in a wide range of sectors, from services to sports, and from education to manufacturing. In the process industries, it arises, for example, in the oil, pharmaceuticals, specialty chemicals, and food and nutraceuticals sectors. Importantly, there is already significant industrial evidence suggesting that the use of advanced optimization methods for scheduling can lead to multimillion-dollar annual savings.

Chemical production scheduling is a relatively new field. The first papers discussing systematic methods appeared in the late 1970s, while the field became one of the major areas of process systems engineering (PSE) only in the late 1990s. Today it is one of the most active research areas in PSE with multiple sessions in national and international chemical engineering conferences dedicated to it and its closely related process operations areas. Its role is only expected to increase as chemical companies move toward product customization and diversification. Despite the volume of papers in the field, however, there is no book discussing the subject as a whole or a book that can be used for a senior-/graduate-level course.

Accordingly, the book is written with two goals in mind. First, it presents a general framework for chemical production scheduling by (1) unifying the notation that has been used by different communities; (2) presenting a classification of the various types of problems and models that have been proposed to address them; and (3) introducing some general principles. Second, it presents the major, modeling and computational, advances in the field over the last 30 years. The book focuses on representative methods and results, but each chapter ends with a discussion of the relevant literature.

Audience

The book is aimed at (1) researchers working in the area of chemical production scheduling or, more broadly, process systems engineering; (2) graduate students interested in the topic; and (3) industrial practitioners. Chemical engineering, industrial engineering, and computer science students are most likely to use this book. The reader is expected to have basic linear algebra knowledge (the equivalent of an undergraduate class in any engineering discipline). Readers with a bachelor of science (BS) degree in engineering or natural sciences will be able to follow the book. The book can also be potentially used in two courses: (1) as one of the main resources for a senior/graduate course on process systems engineering or process optimization/operations, and (2) as the main text for a graduate elective course on chemical production scheduling.

Organization

In broad terms, the book is divided into four parts:

(I) "Background" (Chapters 1 and 2): Chapter 1 presents an introduction to chemical production scheduling, while Chapter 2 presents some background on mixed-integer linear programming.

(II) "Basic Methods" (Chapters 3 through 7): Basic concepts and models for the most encountered classes of problems.

(III) "Advanced Methods" (Chapters 8 through 11): Concepts and models for more complex classes of problems.

(IV) "Special Topics" (Chapters 12 through 15): Advanced solution methods (Chapters 12 and 13), real-time scheduling (Chapter 14), and integration of production planning and scheduling (Chapter 15).

Parts I and II can be used for a senior-/graduate-level semester-long (fifteen-week) course on process operations/optimization. Parts I through III and, potentially, a selection of topics from Part IV can be used for a graduate-level semester-long course on chemical production scheduling.

Approach

One interesting characteristic of scheduling in general, and chemical production scheduling in particular, is that problems arise in many different types of facilities (what we will later define as *production environments*) and can be subject to a wide range of different processing features and constraints, resulting in many different classes of problems. In addition, since the optimization of these systems is challenging, researchers have proposed very different models to address these problems, where a model is typically applicable to a narrow set of problems. Consequently, to present a unified treatment of chemical production scheduling, we had to overcome two major challenges: (1) identify the key concepts, underpinning all problem classes and models, and unifying themes, across all methods; and (2) introduce the reader to different problems and models while keeping the presentation succinct. To address these challenges, the book adopts five basic principles.

First, the presentation is based on, essentially, a road map introduced in Chapter 1. The road map has two components: a classification of scheduling problems (discussed in Section 1.3) and a classification of models (discussed in Section 1.5).

Second, the complexity of covered problems, and corresponding concepts and methods, increases gradually: from single-unit problems, introduced in Chapter 3; to problems in network environments, discussed in Chapter 7; to some *advanced* problems, in Chapters 8 through 11; and then to special topics, in Chapters 12 through 15.

Third, new problem features, and the corresponding concepts, are gradually introduced; for example, batching decisions are introduced in Chapter 3, general resource constraints are introduced in Chapter 4, storage considerations are introduced in Chapter 5, and so on.

Fourth, the book starts with a broad coverage of alternative modeling approaches, so the reader is exposed to most of them, but gradually focuses on fewer approaches, so that more classes of problems can be covered. For example, five ways to model sequencing/timing are discussed in Chapter 3, but only one such approach is discussed in Chapter 8.

Finally, figures are used strategically to explain complex concepts, so that the reader is not distracted by the details pertaining to these concepts. The reader can continue reading and, if interested, return to study the corresponding figures, often containing multiple panels, separately from the text. In that respect, some figures are designed to serve as standalone illustrative examples.

Each chapter includes a "Notes and Further Reading" section where the reader can find additional background information, high-level discussion of extensions of the methods presented in each chapter, and references to related sources. Also, each chapter, except for Chapters 1 and 8, ends with an "Exercises" section, where effort has been made to keep the necessary data to a minimum while covering a wide range of methods discussed in the corresponding chapter. Additional exercises will become available online (see "Online Resources"). Finally, footnotes are used extensively for terminology and notation clarifications; cross-references to related material covered in different chapters; and disambiguation. They are also used to pose questions that are designed to facilitate the understanding of the material.

In terms of notation, each letter is used consistently throughout the book to denote the same parameter or variable, with few exceptions, noted. Also, starting in Chapter 3, we use lowercase Latin characters for indices, uppercase Latin bold letters for sets, uppercase Latin characters for variables, Greek letters for parameters, and regular uppercase Latin letters for set elements.

Online Resources

Additional exercises and some updated auxiliary material (e.g., list of software tools for the development of scheduling methods, all images of the book) are available at cambridge.org/9781107154759. Additional resources can be made available, upon request, to course instructors.

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