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Book review

Scheduling: Theory, Algorithms, and Systems

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Machine scheduling is a classical topic in operations research and operations management. Given the popularity of the 'Just-in-time' philosophy and Total Quality Management, on-time delivery has become a critical factor for customer satisfaction. Scheduling plays an important role in achieving on-time delivery. Over the past four decades, many papers have been published in this area. Recently several books on various aspects of scheduling have been published. This is one that I recommend for both students and professionals in industrial engineering.

The book provides a comprehensive view of scheduling, broad enough to introduce undergraduate students to all the related topics and methodologies, and deep enough to serve as a valuable reference for the researcher or practitioner. From deterministic to stochastic models, from classical scheduling theory to artificial intelligence and computer science, from theoretical description to practical applications, the book offers an excellent overview of the scheduling field. While the author provides an in-depth study of scheduling theory appropriate for researchers and graduate students, basic material is presented clearly and supported by a rich variety of exercises at the end of each chapter, so the book can also be used as a senior-level textbook. In addition, there is an applications section that is a valuable reference tool for practicing industrial managers.

Contents

The book is organized in three sections: Part I deals with deterministic models, Part II deals with stochastic models, and Part III demonstrates some applications. There are also six appendixes.

In the introduction the author explains the importance of scheduling by illustrating three real-life applications: (i) manufacturing scheduling, (ii) scheduling in a service industry, (iii) scheduling in a computer system. The introduction, which also includes a discussion of the place of scheduling within an organization, provides a good motivation for the subject.

Part I (Chapters 2–7) covers classical deterministic models, including single machine, parallel machine, flow shops and flexible flow shops, open shop and job shop scheduling.

Chapter 2 introduces the notation and framework, with examples. It also discusses classes of scheduling problems. Although the author does not give a great deal of motivation, this chapter introduces the concepts of nondelay, active and semiactive schedules. Complexity hierarchy is also introduced in this chapter, which is particularly suitable for graduate students.

Chapter 3 studies the single-machine scheduling problem in the classical structure as most scheduling books do. Four objective functions are included in this chapter: the total weighted completion time, the maximum lateness, the number of tardy jobs, and the total weighted tardiness. Total setup time is also covered. Total weighted completion time is examined under different conditions: with and without precedence constraints, with job release time, with preemption, and with discounted cost. The author then moves to the lateness-related performance measures, including the special case of maximum lateness. The problem with release times is well known to be NP-hard, and hence a branch-and-bound solution is shown. An algorithm to minimize the number of tardy jobs is also provided. The total tardiness problem has been proved to be NP-hard, so pseudo-polynomial dynamic programming is used to solve it. The total weighted tardiness problem is strongly NP-hard, so dominance properties and a branch-and-bound algorithm are presented. Finally, the problem of minimizing makespan with sequence-dependent setup times is formulated as a traveling-salesman problem. Instead of discussing simpler heuristics for the general case, such as the Nearest Neighbor Algorithm, a rather complicated exact algorithm for solving a special case of the problem is provided.

Chapter 4 studies the problem with makespan and total completion time as of scheduling parallel machines with performance measures, with and without preemption. Optimal algorithms, such as the Shortest Processing Time method for the total completion time problem, and heuristic methods and their error bounds, such as the Longest Processing Time for the makespan problem and Weighted Shortest Processing Time for the total weighted completion time problems, are discussed. Several special cases of the precedence constrained problems are discussed, including intree and outtree con-

straints and project scheduling. A polynomial time optimal algorithm is provided to solve the problem with preemption.

Chapter 5 studies the classical flow shop, where each stage has only a single machine, and the flexible flow shop, where each stage can have more than one machine. Optimal properties for the flow shop problem and Johnson's algorithm for the two-machine problem are discussed, as well as a heuristic method for the general flow shop problem. The flow shop with limited intermediate storage is also discussed. The chapter ends with a brief discussion of a special case of the flexible flow shop. Open shop and job shop scheduling are considered in Chapter 6. The two-machine open shop, one of a few polynomially solvable problems in the scheduling area, is first discussed. The problem with more than two machines is NP-hard except for the preemptive case. For the job shop problem, the two-machine problem is also solvable but the remaining problems are very difficult. The shifting bottleneck heuristic is provided with an excellent example to demonstrate the solution procedures.

Chapter 7 discusses general-purpose procedures for deterministic scheduling. This is an interesting and important chapter for applications. Four approaches are discussed in this chapter. The first approach develops composite dispatching rules by combining priority dispatching rules such as those discussed in the previous chapters. The second class of approaches is those based on local search techniques, including simulated annealing, tabu search and genetic algorithms. Filtered beam search, a heuristic modification of branch-and-bound that aims to prune the search tree in an intelligent way, and constraint-guided heuristic search, a technique derived from artificial intelligence, are also discussed.

Part II (Chapters 8–11) covers stochastic models, including single-machine, parallel-machine, flow shop, open shop and job shop models. Although most results are based on the assumption of exponentially distributed problem parameters that may not hold in the manufacturing environment, this part provides basic concepts and possible research topics in stochastic models. Chapter 8 starts with an introduction to and motivation for stochastic models. After introducing notation, the author reviews classes of distributions, and provides several definitions of stochastic dominance, including almost-surely larger, larger likelihood ratio sense, stochastically larger, and larger in expectation, which lead to various implications. Other forms of dominances based on the variability of the random variables under the assumption that the means are equal are also discussed with their implications.

More general forms of dominance known as increasing convex ordering are also presented. The chapter ends with the definition of static list policies (where the decision maker orders the jobs at time 0 according to a priority list and this priority list does not change during the evolution of the process) and dynamic policies (where each time a machine is freed the decision maker is allowed to determine which job goes next).

Chapter 9 examines the stochastic single-machine model. The author first discusses whether finding the optimal policy for the stochastic problem is equivalent to solving a deterministic scheduling problem. Hierarchy of scheduling rules is demonstrated and arbitrary distributions with and without preemptions are discussed in detail. The chapter then turns to likelihood ratio ordered distributions. Interesting results for the exponential distributions are then demonstrated.

Chapter 10 studies parallel-machine models. The results focus on the expected makespan, the total expected completion time and the expected number of tardy jobs. The discussion is limited to exponential or exponential related distributions, and most cases are limited to the two-machine case. For the makespan problem, the interchange rule is used to prove the optimality for the longest expected processing time (LEPT) algorithm and dynamic programming is used to solve the problem for nonpreemptive and preemptive cases respectively. For the total expected completion time problem (with stochastically ordering assumption), the shortest expected processing time (SEPT) method minimizes the total completion time. This chapter also discusses the special case where processing time is equal to one for all jobs and due date is distributed for the due-date-related objective functions.

Chapter 11 studies flow shops, open shops and job shops. For the two-machine flow shop, an elegant solution is developed. For the m-machine problem, a SEPT–LEPT algorithm is discussed in detail for several special cases. For the open shop two-machine problem, an optimal solution is developed for a special case. For the job shop two-machine problem, the result is similar to that of the deterministic case.

PART III covers applications, and aims at reporting how scheduling theory has impacted the real world. Although limited, some interesting industrial applications are provided, especially from the author's own experience in a paper bag company. As the author mentions in the preface, this section should be expanded in the second edition.

Chapter 12 first points out a number of practical scheduling problems that have either been missed or oversimplified in academic research. The remaining part of this chapter deals with examples of real-world problems for which scheduling theory has turned out to be useful. These problems include 'cyclic scheduling of a flow line', 'scheduling of a flexible flow line with limited buffers and bypass', 'scheduling of a flexible flow line with unlimited buffers and setups', and 'sche-

duling of a bank of parallel machines with release dates and due dates'.

Chapter 13 describes how to embed scheduling procedures in a system so that the schedulers can actually apply it. This chapter focuses on issues dealing with the design, development, and implementation of scheduling systems. Systems architecture, databases and knowledge bases, schedule generation issues, and user interfaces are major topics of this chapter. Generic systems versus application-specific systems, and implementation issues, are also discussed.

Chapter 14, the last chapter of the book, provides several case studies of scheduling systems including (i) the AHP Leistand developed in Germany and installed mostly in Western Europe, (ii) the Bagpak production scheduling system (BPSS) developed by International Paper for its Kraft Packaging division, (iii) the gate allocation and tracking expert system (GATES) developed for the TWA terminals at JFK airport in New York and at the St Louis International Airport, and (iv) the Columbia University Interactive Scheduling Editor (CUISE) 2.0 system, an academic prototype. Appendixes deal with Mathematical programming, Deterministic and stochastic dynamic programming, Complexity theory, Complexity classification of deterministic scheduling problems, Overview of stochastic scheduling problems, and Selected scheduling systems.

Comments and recommendations

This book covers basic scheduling theory well enough to serve as a textbook, yet is also deep enough to be useful to researchers. With good illustrations of applications and system design, the book will also be a valuable reference tool for industrial managers. It is well written, well organized, and contains excellent examples, illustrations, and exercises.

The book contains a good number of stochastic models. Instead of using the queuing theory approach, the author uses a deterministic approach. Although most results are based on an exponential distribution, which may not hold in the manufacturing environment, Part II does provide basic concepts and possible research topics in stochastic models.

The scheduling field has been criticized for being too theoretical, using oversimplified models that have little relevance to real world applications. In the past four decades, very few successful scheduling applications have been reported in the literature. However, in recent years this has started to change. Owing to the great progress in computer hardware and software, more and more industrial applications have started to appear in the literature. Part III, which addresses these issues, makes this a unique and very valuable book.

Aside from the above comments, one may wonder whether this book can be used as a text for an undergraduate class. It can, but the instructor must choose the material carefully. For example, the complexity issues would be appropriate only for graduate students. Computational exercises would be good for undergraduates, whereas theoretical problems would be best for a graduate class. Although all the material can be covered in a graduate class, for undergraduate students the instructor needs to select basic topics, emphasize the motivation, and perhaps cover heuristic approaches to some NP-hard problems. In some textbooks the author indicates which sections are basic and which are more advanced. In this book, however, the author has left the choice to the instructor. It will be helpful if the author can provide more basic material, more motivation, and more heuristic approaches in the second edition. Furthermore, indicating which sections are basic and which are more advanced can be convenient to the students.

I recommend this book, both as a textbook and as a reference book. It offers a rich assortment of exercises and problems for students and is unique in its coverage of real-world applications, a perspective that makes it a valuable tool for both researchers and practitioners.

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