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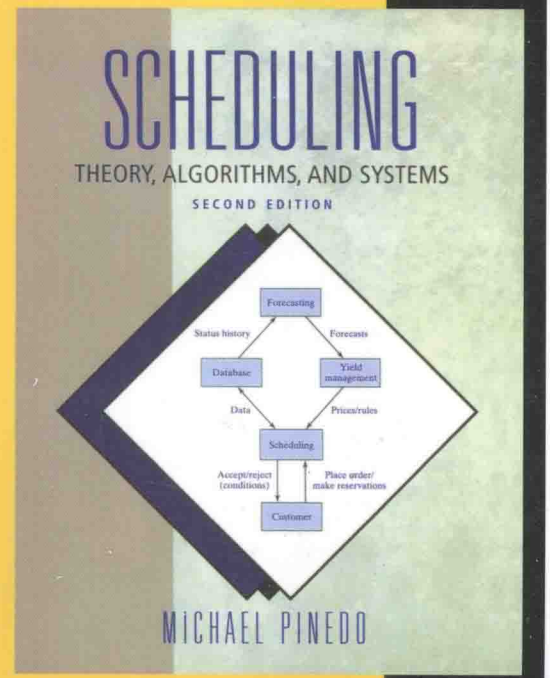
国外大学优秀教材——工业工程系列（影印版）

Michael Pinedo

调度：原理、算法和系统
（第2版）

Scheduling: Theory, Algorithms, and Systems
(Second Edition)



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Education

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Forward

This textbook series is published at a very opportunity time when the discipline of industrial engineering is experiencing a phenomenal growth in China academia and with its increased interests in the utilization of the concepts, methods and tools of industrial engineering in the workplace. Effective utilization of these industrial engineering approaches in the workplace should result in increased productivity, quality of work, satisfaction and profitability to the cooperation.

The books in this series should be most suitable to junior and senior undergraduate students and first year graduate students, and to those in industry who need to solve problems on the design, operation and management of industrial systems.

Gavriel Salvendy

Department of Industrial Engineering, Tsinghua University

School of Industrial Engineering, Purdue University

April, 2002

前　言

本教材系列的出版正值中国学术界工业工程学科经历巨大发展，实际工作中对工业工程的概念、方法和工具的使用兴趣日渐浓厚之时。在实际工作中有效地应用工业工程的手段将无疑会提高生产率、工作质量、合作的满意度和效果。

该系列中的书籍对工业工程的本科生、研究生和工业界中需要解决工程系统设计、运作和管理诸方面问题的人士最为适用。

加弗瑞尔·沙尔文迪
清华大学工业工程系
普渡大学工业工程学院（美国）
2002 年 4 月

Preface to the First Edition

Sequencing and scheduling is a form of decision-making that plays a crucial role in manufacturing and service industries. In the current competitive environment effective sequencing and scheduling has become a necessity for survival in the marketplace. Companies have to meet shipping dates that have been committed to customers, as failure to do so may result in a significant loss of goodwill. They also have to schedule activities in such a way as to use the resources available in an efficient manner.

Scheduling began to be taken seriously in manufacturing at the beginning of this century with the work of Henry Gantt and other pioneers. However, it took many years for the first scheduling publications to appear in the industrial engineering and operations research literature. Some of the first publications appeared in *Naval Research Logistics Quarterly* in the early 1950s and contained results by W.E. Smith, S.M. Johnson, and J.R. Jackson. During the 1960s a significant amount of work was done on dynamic programming and integer programming formulations of scheduling problems. After Richard Karp's famous paper on complexity theory, the research in the 1970s focused mainly on the complexity hierarchy of scheduling problems. In the 1980s several different directions were pursued in academia and industry with an increasing amount of attention paid to stochastic

scheduling problems. Also, as personal computers started to permeate manufacturing facilities, scheduling systems were being developed for the generation of usable schedules in practice. This system design and development was, and is, being done by computer scientists, operations researchers and industrial engineers.

This book is the result of the development of courses in scheduling theory and applications at Columbia University. The book deals primarily with machine scheduling models. The first part covers deterministic models and the second part stochastic models. The third and final part deals with applications. In this last part scheduling problems in practice are discussed and the relevance of the theory to the real world is examined. From this examination it becomes clear that the advances in scheduling theory have had only a limited impact on scheduling problems in practice. Hopefully there will be, in a couple of years, a second edition in which the applications part will be expanded, showing a stronger connection with the more theoretical parts of the text.

This book has benefited from careful reading by numerous people. Reha Uzsoy and Alan Scheller Wolf went through the manuscript with a fine-tooth comb. Len Adler, Sid Browne, Xiuli Chao, Paul Glasserman, Chung-Yee Lee, Young-Hoon Lee, Joseph Leung, Elizabeth Leventhal, Rajesh Sah, Paul Shapiro, Jim Thompson, Barry Wolf, and the hundreds of students who had to take the (required) scheduling courses at Columbia provided many helpful comments that improved the manuscript.

The author is grateful to the National Science Foundation for its continued summer support, which made it possible to complete this project.

MICHAEL PINEDO
New York, 1994

Preface to the Second Edition

The book has been extended in a meaningful way. Five chapters have been added. In the deterministic section it is the treatment of the single machine, the job shop, and the open shop that have been expanded considerably. In the stochastic section a completely new chapter focuses on single machine scheduling with release dates. This chapter has been included because of multiple requests from instructors who wanted to see a connection between stochastic scheduling and priority queues. This chapter establishes such a link. Part III, the applications section, has been expanded the most. Instead of a single chapter on general-purpose procedures, there are now two chapters. The second chapter covers various techniques that are relatively new and that have started to receive a fair amount of attention over the last couple of years. There is also an additional chapter on the design and development of scheduling systems. This chapter focuses on rescheduling, learning mechanisms, and so on. The chapter with the examples of systems implementations is completely new. All systems described are of recent vintage. The last chapter contains a discussion on research topics that could become of interest in the next couple of years.

There is a companion website for this book:

http://www.stern.nyu.edu/~mpinedo

The intention is to keep the site as up-to-date as possible, including links to other sites that are potentially useful to instructors as well as students.

Many instructors who have used the book over the last couple of years have sent very useful comments and suggestions. Almost all of these comments have led to improvements in the manuscript.

Reha Uzsoy, as usual, went through the manuscript with a fine-tooth comb. Salah Elmaghraby, John Fowler, Celia Glass, Chung-Yee Lee, Sigrid Knust, Joseph Leung, Chris Potts, Steve Smith, Levent Tuncel, Amy Ward, Guochuan Zhang, Subhash Sarin, and Wilbert E. Wilhelm all made comments that led to substantial improvements.

A number of students, including Gabriel Adei, Yo Huh, Maher Lahmar, Sonia Leach, Michele Pfund, Edgar Possani, and Aysegul Toptal, have pointed out various errors in the original manuscript.

Without the help of a number of people from industry, it would not have been possible to produce a meaningful chapter on industrial implementations. Thanks are due to Heinrich Braun and Stephan Kreipl of SAP, Rama Akkiraju of IBM, Margie Bell of i2, Emanuela Rusconi and Fabio Tiozzo of Cybertec, and Paul Bender of SynQuest.

MICHAEL PINEDO
New York, 2001

Contents

1

Introduction

1.1 THE ROLE OF SCHEDULING

Scheduling deals with the allocation of scarce resources to tasks over time. It is a decision-making process with the goal of optimizing one or more objectives.

The resources and tasks in an organization can take many forms. The resources may be machines in a workshop, runways at an airport, crews at a construction site, processing units in a computing environment, and so on. The tasks may be operations in a production process, take-offs and landings at an airport, stages in a construction project, executions of computer programs, and so on. Each task may have a certain priority level, an earliest possible starting time, and a due date. The objectives can also take many forms. One objective may be the minimization of the completion time of the last task, and another may be the minimization of the number of tasks completed after their respective due dates.

Scheduling is a decision-making process that plays an important role in most manufacturing and production systems as well as in most information-processing environments. It also exists in transportation and distribution settings and in other types of service industries. The following three examples illustrate the role of the scheduling process in real-life situations.

Example 1.1.1 (A Paper Bag Factory)

Consider a factory that produces paper bags for cement, charcoal, dog food, and so on. The basic raw material for such an operation is rolls of paper. The production process consists of three stages: the printing of the logo, the gluing of the side of the bag, and the sewing of one end or both ends of the bag. At each stage, there are a number of machines that are not necessarily identical. The machines at a stage may differ slightly in the speed at which they can run, the number of colors they can print, or the size of bag they can handle. Each production order indicates a given quantity of a specific bag that has to be produced and shipped by a committed shipping date or due date. The processing times for the different operations are proportional to the size of the order (i.e., the number of bags ordered).

A late delivery implies a penalty in the form of loss of goodwill, and the magnitude of the penalty depends on the importance of the order or the client and the tardiness of the delivery. One of the objectives of the scheduling system is to minimize the sum of these penalties.

When a machine is switched over from one type of bag to another, a setup time is incurred. The length of the setup time on the machine depends on the similarities between the consecutive orders (the number of colors in common, the differences in bag size, etc.). Another objective of the scheduling system is to minimize the total time spent on setups.

Example 1.1.2 (Gate Assignments at an Airport)

Consider an airline terminal at a major airport. There are dozens of gates and hundreds of airplanes arriving and departing each day. The gates are not all identical and neither are the planes. Some of the gates are at locations with a lot of space where large planes (widebodies) can be accommodated easily. Other gates are in locations where it is difficult to bring in the planes. Certain planes may actually have to be towed to their gates.

Planes arrive and depart according to a certain schedule. However, the schedule is subject to a significant amount of randomness that may be weather related or due to events at other airports. During the time that a plane occupies a gate, the arriving passengers have to be deplaned, the plane has to be serviced, and the departing passengers have to be boarded. The scheduled departure time can be viewed as a due date, and the airline's performance is measured accordingly. However, if it is known in advance that the plane cannot land at the next airport because of anticipated congestion at the scheduled arrival time, then the plane does not take off (such a policy