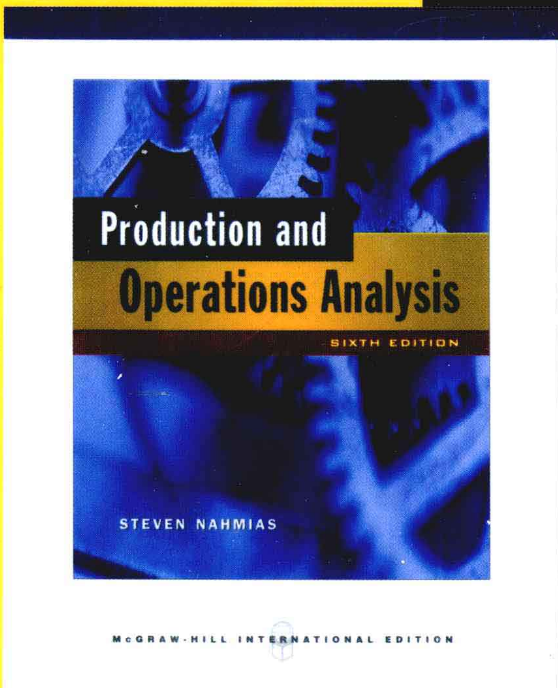
国外大学优秀教材——工业工程系列（影印版）

Steven Nahmias

成晔　改编

# 生产与运作分析

## （第6版）

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# Production and Operations Analysis

## Sixth Edition

# 生产与运作分析

## (第6版)

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北　京

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**Production and Operations Analysis, Sixth Edition**
ISBN: 978-007-126370-2



北京市版权局著作权合同登记号　图字：01-2009-3234 号



**图书在版编目(CIP)数据**

生产与运作分析：第 6 版：英文 /（美）纳罕姆斯（Nahmias, S.）著；成晔改编. —影印本. —北京：清华大学出版社，2009.7
（国外大学优秀教材. 工业工程系列）
ISBN 978-7-302-20347-6

Ⅰ. 生…　Ⅱ. ①纳…②成…　Ⅲ. 企业管理－生产管理－高等学校－教材－英文　Ⅳ. F273

中国版本图书馆 CIP 数据核字（2009）第 094544 号

**责任编辑**：张秋玲
**责任印制**：孟凡玉

**出版发行**：清华大学出版社　　**地　址**：北京清华大学学研大厦 A 座
http://www.tup.com.cn　　**邮　编**：100084
**社 总 机**：010-62770175　　**邮　购**：010-62786544
**投稿与读者服务**：010-62776969, c-service@tup.tsinghua.edu.cn
**质量反馈**：010-62772015, zhiliang@tup.tsinghua.edu.cn
**印 刷 者**：清华大学印刷厂
**装 订 者**：三河市李旗庄少明装订厂
**发 行 者**：全国新华书店
**开　本**：185×230　　**印张**：35.5
**版　次**：2009 年 7 月第 1 版　　**印　次**：2009 年 7 月第 1 次印刷
**印　数**：1~3000
**定　价**：58.00 元

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2009.5

# 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.

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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

# About the Author

**Steven Nahmias** is Professor of Operations and Management Information Systems in the Leavey School of Business and Administration at Santa Clara University. He holds a B.A. in Mathematics and Physics from Queens College, a B.S. in Industrial Engineering from Columbia University, and M.S. and Ph.D. degrees in Operations Research from Northwestern University. He has also served on the faculties of the University of Pittsburgh, Georgia Tech, and Stanford University.

Dr. Nahmias is widely known for his research on stochastic inventory models and has authored or co-authored more than 50 scientific articles which have appeared in a variety of national and international journals. He has served as area editor of Supply Chain Logistics for *Operations Research,* associate editor for *Management Science,* senior editor for *Manufacturing and Service Operations Management,* and is currently associate editor for *Naval Research Logistics.* He received first prize in the 39th Nicholson Student Paper Competition (1971), second prize in the TIMS Student Paper Competition (1972), and is the recipient of The University Award for Sustained Excellence in Scholarship from Santa Clara University (1998).

In addition to his academic activities, Dr. Nahmias has served as a consultant to a variety of firms and agencies including Litton Industries, Xerox Corporation, IBM Corporation, LEX Automotive, and the Department of Transportation of Santa Clara County. Among his several hobbies, he enjoys golf, biking, and plays jazz trumpet with several bands in the Bay Area.

# Preface to the Sixth Edition

While the structure and organization of the text remains essentially the same as in the fifth edition, the current edition includes several new topics. The new material is aimed at enhancing the technical content of the book, and for that reason is more likely to appeal to engineering students and advanced business students. The biggest addition is a section in Chapter 2 on Box-Jenkins models. The Box-Jenkins methodology has proved itself to be a valuable forecasting tool in the right setting. I balked at including this material in past editions because of its complexity. In this edition, I tried to develop a self-contained discussion at a comparable technical level to the rest of the text. Hopefully, this 20-or-so-page addition has accomplished this goal. I would appreciate feedback from those of you that add this material to your coverage of forecasting.

Another addition suggested by current and past reviewers was to include Robin Roundy's power-of-two policies in Chapter 4. While this work has had a major impact on inventory modeling, again there was a question about whether the discussion could be at a level commensurate with the rest of the book. What I have done is to treat power-of-two policies in the context of the simple EOQ model only (as abstracted from one of Roundy's papers). In this way, the student can get a sense of why these policies are able to provide such effective approximations without getting into the details of the more advanced analysis.

In addition to these changes, I have added several new exercises in the early chapters. Much of the expository material has been updated, and many new Snapshot Applications included. My thanks go to all of the loyal users of earlier editions, to the editorial staff at McGraw-Hill, and to the reviewers of the fifth edition including Elif Akcali, University of Florida; Moshe Dror, University of Arizona; Michael Erickson, Albertson College; Serge Karalli, California State University at Sacramento; Reza Khorramshahgol, American University; Rakesh Nagi, University of Buffalo; and Kevin Taaffe, Clemson University. Special thanks to the great team at McGraw-Hill including Scott Isenberg, my long time editor, Dana Pauley, and Katie Jones for their guidance, help, and patience. I would also like to thank Lucy Mullins, the copyeditor, and Ravi Lakhina at Macmillan Publishing Solutions for the great work they did on this edition.

# Introduction

## 1 THE PRODUCTION AND OPERATIONS MANAGEMENT FUNCTION

This book concerns production in the broadest sense of the word: that is, production of both *goods* and *services*. The term *production* has its roots in studies of factory automation. The term *operations management* has become popular in recent years to reflect broader interests. This book is about the analytical methods used to support the production and operations management function. Production and operations management is the process of managing people and resources in order to create a product or a service. Operations involve the logistics required to support the production function.

Marketing, finance, and production are the three major functional areas of the firm. Marketing acts as a buffer to the outside world. It chooses the manner in which products are presented to the consumer and discovers the directions of consumer preferences. Finance is responsible for finding sources of outside funding and managing the capital within the firm. Production is responsible for converting raw materials into products or for providing a specific set of services. The activities of the three functional areas of the firm must be carefully coordinated for the firm to operate efficiently.

Bowman and Fetter (1967) list the following as the major economic problems of production management:

1. Inventory.
2. Production scheduling and control.
3. Equipment selection and replacement.
4. Maintenance.
5. Size and location of plants.
6. Plant layout and structure.
7. Quality control and inspection.
8. Traffic and materials handling.
9. Methods.

Although this list was compiled over 30 years ago, it still accurately represents the most important economic decisions of production management. This text treats each of these areas except for the last two. Although work methods and materials handling are both important topics, they are not areas in which analytical methods have had a significant impact.

## 2 HISTORY OF PRODUCTION MANAGEMENT

According to Skinner (1985), there are five periods of industrial history that stand out in the development of manufacturing management:

| | |
|---|---|
| 1780–1850 | Manufacturing leaders as technology capitalists. |
| 1850–1890 | Manufacturing leaders as architects of mass production. |
| 1890–1920 | Manufacturing management moves down in the organization. |

| | |
|---|---|
| 1920–1960 | Manufacturing management refines its skills in controlling and stabilizing. |
| 1960–1980 | Shaking the foundations of industrial management. |

During the early years of the Industrial Revolution, production began to shift from low-volume activity to larger-scale operations. Although the scale of these early operations was large, the machinery was not particularly complex and production operations were rigid. The management of these operations remained essentially in the hands of top management with the aid of overseers. Working conditions during this period were often abysmal.

The major thrust of the Industrial Revolution took place in the second 40-year period from 1850–1890. During this period, the concepts of mass production and the assembly line were born. Since coal could be efficiently transported, plants could be located in a larger variety of locations. The plant foreman had enormous power and influence during this period.

According to Skinner, the job of production manager actually came into being in the period 1890–1920. Manufacturing processes became too complex to be handled by top-management personnel any longer. With this complexity came the need for scientific management techniques. Frederick Taylor (often called the father of industrial engineering) is generally credited with being the originator of the concept of scientific management. Most of the scientific management techniques introduced around the turn of the century involved merely breaking a task down into its various components. These techniques are probably less scientific than just orderly. With the new levels of complexity, the single plant foreman could no longer coordinate the demands of producing a varied product line and changing production schedules. The age of the specialist was upon us.

The enormous worldwide depression that took place in the 1930s notwithstanding, in many ways the period 1920–1960 can be considered a golden age for the development of industry in the United States. By 1960, the United States was the preeminent economic power in the world. With the growth of the labor movement, working conditions had improved enormously. True scientific methods started finding their way into the factory. Mathematical models for learning, inventory control, quality control, production scheduling, and project management gained acceptance by the user community. Top management often came through the ranks of production professionals during this period.

Since 1960, many American companies have relinquished their domination of certain markets. Products that were traditionally produced in the United States are now imported from Germany, Japan, and the Far East. Many products are produced more cheaply and with higher quality overseas. Furthermore, management–employee relations are often better in foreign companies. Quality circles, introduced in Japan, allowed employees to input opinions about product development and production procedures. Far more sophisticated scientific production methods have been adopted in Japan than in other countries. For example, there are many more robots and modern flexible manufacturing systems in Japan than in the United States.

Production managers will require better training and preparation than ever before. They will have to be well versed in many new technologies and be able to deal with complex information systems and decision support systems. Computers will continue to improve. As powerful computing capability is brought directly to the factory floor, sophisticated mathematical models will play an ever-increasing role in modern production and operations management. The aim of this text is to provide the prospective production professional with the technical tools necessary to face the coming century.

# 3 OVERVIEW OF THE TEXT

Albert Einstein said that physics should be explained as simply as possible, but no simpler. This reflects the philosophy behind this book.

Features of this book include

- Breadth.
- Depth.
- Clarity.
- Modularity.
- Example.
- Reinforcement.
- Historical notes and summaries.
- Spreadsheet problems.
- Snapshot Applications.

Almost every chapter includes material rarely found in survey texts, and some include topics only treated in published articles. The writing is economical, but all concepts are carefully explained. The chapters are designed to stand alone. Many sections can be skipped without loss of continuity, allowing the instructor to tailor the sequencing and the depth of coverage to his or her needs. I make extensive use of examples. Some are case-type examples spanning most of a chapter, while others are short examples used to illustrate a particular concept or technique. I have tried to make the examples realistic enough to show the student how a method would actually be used in practice.

I have chosen to include problems at the end of each section as well as at the end of most chapters. Section problems have two advantages. They give the student immediate reinforcement of the material discussed in that particular section. Also, it is easier for an instructor only covering portions of chapters to assign appropriate problems. There are more than 550 problems in the book.

Each chapter, except the first, includes a section titled "Historical Notes." As a student, I always found textbooks to be somewhat sterile, conveying little of the history of the developments discussed. I think it is interesting to know when and how things were developed. I realize that I am taking a big risk by including these sections, since I may have incorrectly identified some original sources. I encourage knowledgeable readers to let me know if this is the case. The summaries at the end of each chapter will provide the reader with an overview of the material treated in the chapters.

Problems designed to be solved with the aid of a computer (in particular, with a spreadsheet program) are included. These problems are marked with a graphic to identify them and almost always appear in the problem set at the end of the chapters.

How topics should be sequenced is a personal issue. Undoubtedly, many of you would sequence the material differently. My rationale is as follows. The first chapter is primarily expository and provides a nontechnical introduction to the important strategic issues facing firms today. The remainder of the book covers three general areas: inventory (broadly defined), scheduling and facilities design, and quality. The inventory sections include Chapters 2–6, covering forecasting, aggregate planning, deterministic and stochastic single-item systems, and supply chains respectively. MRP and JIT, treated in Chapter 7, overlap with both inventory and scheduling, and provide the link to the next three chapters. These are Chapters 8–10 and include job shop scheduling, project scheduling, and layout and location. The final two chapters treat quality, broadly defined.

Chapter 11 is a very comprehensive treatment of statistical quality control, acceptance sampling, and several additional quality topics. Chapter 12 is a chapter rarely, if ever, found in operations texts. It is my feeling that a comprehensive treatment of quality should include reliability and maintenance as well.

Previous editions of the book have had over 100 adopters from both business and engineering schools. While the book has not lost its quantitative character, revisions have been aimed at widening the audience by adding more qualitative material. The new supply chain chapter does include several quantitative sections but is, by and large, focused on strategic concerns. Because of the book's modular design, it can be adapted easily to the needs of the instructor. The first six chapters can serve as a reasonable one-quarter course on inventory and related topics; Chapters 7–10 provide a reasonable treatment of scheduling including MRP and JIT; and the last two chapters could form the basis for a course in quality and reliability. Alternatively, a survey course could be comprised of a few sections from each chapter. I believe there is sufficient material in the text for a two-quarter or two-semester sequence as well.

# 4 OVERVIEW OF EACH CHAPTER

## Chapter 1. Strategy and Competition

Chapter 1 provides a brief overview of the significant issues in competition and operations strategy. The introduction positions manufacturing strategy as part of the overall business strategy of the firm. Section 1 considers the issue that we are evolving into a service economy and the concerns that this should engender if true. Section 2 provides an overview for the general framework for strategic issues. Section 3 considers the classic view of operations strategy developed by B. F. Skinner of Harvard. Section 4 considers issues arising from globalization of manufacturing and includes a new Snapshot Application on global manufacturing strategies in the automobile industry. Sections 5 to 8 consider several modern strategic initiatives undertaken in recent years. These include business process reengineering, just-in-time, the emphasis on quality, and time-based competition. Section 9 considers the product life cycle and how product and process life cycles need to be matched.

Section 10 treats learning and experience curves. These are certainly of strategic importance to anyone interested in projecting costs and efficiencies. The final section of Chapter 1 treats models for planning for capacity growth. This section also includes a qualitative discussion of some of the issues that arise in plant location decisions (mathematical models used for making location decisions are discussed in depth in Chapter 10).

## Chapter 2. Forecasting

This chapter provides an in-depth treatment of this important topic. Care has been taken to provide both a rigorous treatment of the topic and one that is accessible to a wide audience. Issues such as the periods from and to which one forecasts are considered.

The first four sections of the chapter include an expository discussion of several important forecasting issues. In Sections 5 and 6 the notation used throughout the chapter is introduced and measures of performance are defined. Section 7 is devoted to a discussion of the most popular methods for predicting stationary series including simple moving averages and simple exponential smoothing. The difference between one-step-ahead and multiple-step forecasts is made clear. Also a careful comparison between exponential smoothing and moving averages is made. We discuss consistent values of $N$ for moving averages and $\alpha$ for exponential smoothing in Appendix A and prove that consistent values of these parameters result from equating the variance of forecast errors. The Snapshot Application at the end of Section 7 discusses Sport Obermeyer's sophisticated forecasting system.

Section 8 considers methods for forecasting series in which a linear trend is present. We consider simple linear regression and Holt's method. Undoubtedly, there are many other methods that we could have considered, but these seemed to be the most representative. Holt's method is presented rather than R. G. Brown's double exponential smoothing since, in the opinion of this writer, Holt's method is more intuitive.

Section 9 considers methods for seasonal series. We present a popular method for deseasonalizing a series using moving averages and a careful and detailed exposition of Winters's exponential smoothing method for seasonal series. Few texts at this level consider Winters's method. Section 10, new with the sixth edition, considers Box-Jenkins models. ARIMA (Autoregressive, integrated moving average) models are very powerful for prediction of stationary time series when a substantial history of data is available. Section 11 considers several practical issues when implementing forecasting methods. Section 12 provides a brief overview of advanced methods including forecasting in the presence of lost sales. Section 13 discusses the distinction between variance of demand and variance of forecast error. This issue is also treated in Chapter 5.

## Chapter 3. Aggregate Planning

This chapter presents a comprehensive treatment of aggregate planning and considers several issues generally overlooked. One is the meaning of an aggregate unit of production. Students are often confused about the difference between normal units and aggregate units and few authors explain this difference. Prior to introducing the aggregate planning methodology, we discuss the need for aggregate planning and the relevant costs, and introduce a case-type problem used throughout the chapter.

Section 4 considers the two simplest aggregate plans: constant workforce plan and the zero inventory plan. The application of linear programming to aggregate planning is carefully developed. Since aggregate planning is an integer programming problem, rounding considerations cannot be ignored. We present a detailed example with computer outputs to illustrate the proper steps in rounding.

Sections 7 and 8 consider the HMMS Linear Decision Rule and Bowman's management coefficients. The material on disaggregating aggregate plans in Section 9 is rarely discussed in most texts and includes a Snapshot Application. Section 10 considers global issues in aggregate planning.

## Supplement 1. Supplement on Linear Programming

This supplement differs from the chapters only in that there are no problems. The purpose of this supplement is to bring the student up to speed on linear programming for those who may not have been exposed to this important area. As more business programs drop the management science requirement, POM texts will have to include material traditionally taught in these courses. This supplement is more detailed than most and is designed to give the student sufficient background on the *application* (as opposed to the theory) of LP to be able to apply it. A comprehensive discussion of Solver is included, in recognition that Solver is now the de facto standard.

## Chapter 4. Inventory Control Subject to Known Demand

Chapters 4 and 5 treat inventory models in depth. Sections 1, 2, and 3 of Chapter 4 present an expository description of types of inventories, motivation for holding inventories, and characteristics of inventory control systems. Section 4 presents a detailed discussion of the forms of the cost functions on which the models for Chapters 4 and 5 are based. The treatment of the simple EOQ model in Section 5 includes discussions of sensitivity analysis and order lead times. Section 6 treats the extension of the simple EOQ to the case of a finite production rate.

Section 7 concerns quantity discount models including both all units and incremental discounts. The material of Section 8, resource-constrained multiple product systems, is rarely found in OM texts. In this section we show under what circumstances such problems can be solved easily and under what circumstances Lagrange multipliers are required. Section 9 on EOQ models for production planning considers the interface between production scheduling and classical inventory models. Section 10 provides a brief overview of power-of-two policies. The Snapshot Application highlights Mervyn's successful inventory control system.

## Chapter 5. Inventory Control Subject to Uncertain Demand

This chapter presents a detailed and comprehensive treatment of stochastic inventory models. It begins with a general discussion of randomness in the context of inventory control and presents a case example that is used to illustrate methodologies presented in the remainder of the chapter. A rigorous derivation of the newsboy model is included as well as a careful discussion of the interpretation of costs. In this presentation I have chosen the overage and underage cost formulation instead of the formulation with order, holding, and penalty costs that one finds in many OR texts. I have found this particular formulation easier for the student to understand and apply. A unique feature of our coverage is the extension of the newsboy model to multiple planning periods.

Section 4 is a comprehensive treatment of lot size–reorder point models. Models of this type form the basis for many commercial inventory control systems. The section begins with definitions and descriptions of variables and costs. Section 5 treats service levels and the difference between setting the probability of not stocking out in the lead time and the fill rate, an important distinction. Other issues discussed in this section include scaling of lead time demand, imputed shortage cost, linking of inventory and forecasting, and random lead times.

Although a formal derivation of $(s, S)$ policies is beyond the scope of this text, $(s, S)$ policies are mentioned along with a brief discussion of service levels in periodic review systems. Section 7 considers ABC analysis and exchange curves for multiproduct inventory systems. The chapter concludes with a summary of several advanced topics in inventory modeling.

There are five appendices to Chapter 5. I recommend that instructors be aware of the material contained there as they may wish to include it in their lectures. Appendix 5–A is a basic probability review. Appendix 5–B adds considerable technical depth to the discussion of the newsboy model, including the correct interpretation of overage and underage costs for infinite horizon versions of the backorder and the lost sales cases. Appendix 5–C provides details of the derivation of the $(Q, R)$ policy. Appendix 5–D extends the models treated in the chapter to the Poisson and Laplace distributions.

## Chapter 6. Supply Chain Management

This chapter provides a comprehensive overview of the key topics in this important new area of operations management. The chapter starts with definitions and a Snapshot Application featuring Wal-Mart. Sections 1–4 of the chapter consider the transportation problem, generalizations, and more general network formulations of transshipment problems. Using Excel to solve these problems is also treated in this section. Section 4 concludes with a Snapshot Application of IBM's spare parts management system.

Section 5 treats the DRP approach to resource planning. Section 6 is on vehicle routing. Section 7 is on product design for supply chains. Dell Computer is featured in the Snapshot Application in this section.

Section 8 discusses the role of information in supply chains. This section includes a discussion of the bullwhip effect. In Section 9, I discuss some of the multi-echelon inventory models and how they relate to modern supply chain issues. In Section 10, I discuss some of the important global issues that must be taken into account when designing a supply chain and trends in offshore outsourcing. The chapter concludes with another Snapshot Application featuring DEC's global supply chain design.

## Chapter 7. Push and Pull Production Control Systems: MRP and JIT

We treat MRP and JIT as two philosophies for manufacturing control. The first half of the chapter treats MRP and lot sizing. This chapter has several unique features. One is that dynamic lot sizing is included here rather than in Chapter 4 or in a separate chapter on production planning. In this way the importance of lot sizing in MRP can be made clear. How lot sizing at one level affects the pattern of requirements at lower levels is often overlooked in presentations of this material.

A case study is presented to show how the explosion calculus works. The example is carried through to three levels of the product structure. Optimal lot sizing using the Wagner–Whitin algorithm has been relegated to Appendix A and can be skipped without loss of continuity. We consider Silver–Meal, least unit cost, and part period balancing heuristics as well. (The period order quantity heuristic is also discussed in the problems.) By presenting these lot sizing algorithms here, we can show how lot sizing decisions impact on the materials requirements plan at the various levels of the product structure. Also, we present an original heuristic (similar to others that have appeared in the literature) for constrained lot sizing.

Section 7 provides an in-depth treatment of JIT. Some of this material appeared in Chapter 12 of earlier editions, but there are several new topics as well, including SMED and CONWIP. MRP and JIT philosophies are compared and contrasted. The chapter concludes with a comparison of JIT and lean production.

## Chapter 8. Operations Scheduling

This chapter presents an overview of the most important results for sequence scheduling. The effect of sequencing rules on several measures of performance is made clear by presenting a detailed example showing the effect of the four sequencing rules: first-come first-served, shortest processing time first, earliest due date, and critical ratio. Several algorithms for single machine sequencing are presented, including Moore's algorithm for minimizing the number of tardy jobs and Lawler's algorithm for precedence constraints.

The next portion of the chapter considers sequencing algorithms for multiple machines. We present Johnson's algorithm for both two and three machine scheduling and Aaker's graphical procedure for two jobs on *m* machines. This is probably the only text also to consider results for stochastic scheduling. We present several of the more elegant results in this area and include some proofs to enhance the student's understanding of the material. This chapter also includes a discussion of stochastic scheduling in a dynamic environment. This section is an application of queuing theory to sequence scheduling.

The last major topic considered in Chapter 8 is assembly line balancing. We present only one heuristic for solving the problem: the ranked positional weight technique. The section discusses experimenting with different values of the cycle time in order to achieve an optimal balance.

A brief review of post-MRP scheduling software is provided here, as well as an overview of using simulation for scheduling. The Snapshot Application provides descriptions of several successful scheduling initiatives in the real world.

## Supplement 2. Supplement on Queuing Theory

This material supports the section on dynamic stochastic scheduling in Chapter 8 by providing the student with a good overview of queuing theory. It includes a derivation of the steady-state probability for the M/M/1 queue and results without proof for more complex models. As with the LP Supplement, it should be helpful to students who have not been exposed to queuing theory elsewhere.

## Chapter 9. Project Scheduling

This chapter begins with a description of the project scheduling problem and how projects are represented as networks. A case study is introduced to illustrate the methodologies discussed throughout the remainder of the chapter. We present the details of CPM including the calculation of earliest and latest start and finish times as well as identification of the critical path. Time costing methods also are considered in Section 4.

The PERT method for handling random activity times is treated in Section 5. The traditional PERT approach, which assumes that the length of the critical path has the normal distribution and is the path with the longest *expected* activity time, is presented. An alternative approximation is to assume that the times required to complete two or more paths are independent random variables. In some cases, the assumption of path independence could give more accurate results than the traditional PERT approach, which assumes that the path with the longest expected value is the longest path.

This chapter also includes material rarely covered in production texts. We show by example how one incorporates resource constraints into the standard project planning framework and how one constructs resource loading profiles. This chapter also includes a section showing how one would apply linear programming to solve project scheduling problems. In addition to linear programming, one also could use special-purpose project scheduling software, reviewed here. Organizational structures to facilitate project management also are discussed, as well as PC project management software.

## Chapter 10. Facilities Layout and Location

Chapter 10 is a comprehensive treatment of the major developments in the area of layout and location. It makes liberal use of examples to illustrate complex methodology. We discuss the traditional charts for assisting with layout decisions, including the from-to chart and the rel chart. In Section 4 we show how one uses the simple assignment model for solving location problems in which there is no interaction among facilities, and only a small set of alternative locations. The quadratic assignment model for solving more complex problems also is presented, although the details of implementing the algorithm are beyond the scope of this text.

Section 6 presents a detailed description of CRAFT. We show how centroids (used by CRAFT) are computed in Appendix A of the chapter and apply the method to a specific example. Other computerized layout methods are considered in less detail: these include COFAD, ALDEP, CORELAP, and PLANET. This section concludes with an interesting debate from the literature about whether computers or humans find better layouts.

In Sections 8 through 11 of Chapter 10 we treat the problem of locating new facilities. We consider qualitative location issues treated in detail in Chapter 1 as part of our discussion of strategy, so that discussion is not repeated here. In Section 9 we discuss the method for locating one new facility subject to a rectilinear distance measure. Other topics considered in this section include contour lines and a minimax objective rather than a weighted objective. Squared Euclidean and Euclidean distance measures are considered in Section 10. In Section 11 we include brief discussions of several other extensions including models for locating multiple facilities, location-allocation problems, discrete location models, and network location models.

## Chapter 11. Quality and Assurance

This chapter is one of the longer ones in the text and presents a detailed coverage of the important techniques and issues in the quality area. The first part of the chapter is devoted to control charts. A brief review of the relevant results from probability theory is presented first. As with most of the other techniques discussed in the text, we start the section with a case-type example. The case is used to illustrate the construction of both $\overline{X}$ and $R$ charts. A point discussed in Section 2 often overlooked in other presentations of this material is the interpretation of Type 1 and Type 2 errors in the context of control charts. Both $p$ and $c$ charts are discussed as well.

Section 6 includes material rarely found in survey texts, namely the economic design of $\overline{X}$ charts. Assuming costs for sampling, searching for an assignable cause, and operating out of control are known, we show how to find the minimum expected cost design of the $\overline{X}$ chart. The theory is illustrated with one of the chapter's case examples.

The second part of the chapter is devoted to acceptance sampling. Again a case example is introduced to illustrate the methodology. We discuss single sampling plans, double sampling plans, and sequential sampling plans. Also included in this section is a detailed treatment of average outgoing quality with derivations of the various formulas. The chapter concludes with a discussion of several popular management methods for improving quality including quality circles, total quality control, and zero defects.

Section 13 provides a discussion of total quality management including definitions, competition based on quality, organizing for quality, benchmarking quality, and a discussion of the Deming Prize and the Baldrige Award. Also included here are sections on listening to the customer and quality function deployment. Section 14 examines the interface between quality and design and the application of Taguchi methods.

## Chapter 12. Reliability and Maintainability

Although reliability and maintainability are considered to be part of the body of information comprising production and operations management, few survey texts include