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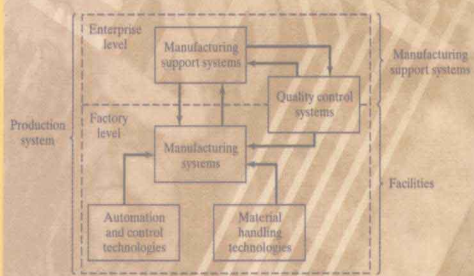
Mikell P. Groover

自动化、生产系统与计算机集成制造（第2版）

Automation, Production Systems, and Computer-Integrated Manufacturing (Second Edition)

Automation,
Production Systems,
and
Computer-Integrated
Manufacturing

Second Edition



PEARSON Education

清华大学出版社

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Automation, Production Systems, and Computer-Integrated Manufacturing

SECOND EDITION

自动化、生产系统与计算机集成制造

（第2版）

Mikell P. Groover

Professor of Industrial and Manufacturing Systems Engineering Lehigh University

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Preface

The first edition of this book was published in 1980 under the title ***Automation, Production Systems, and Computer-Aided Manufacturing***. A revision was published in 1987 with about 200 more pages and a slightly different title: ***Automation, Production Systems, and Computer Integrated Manufacturing***. The additional pages expanded the coverage of topics like industrial robotics, programmable logic controllers, material handling and storage, and quality control. But much of the book was very similar to the 1980 text. By the time I started work on the current volume (technically the second edition of the 1987 title, but in fact the third generation of the 1980 publication), it was clear that the book was in need of a thorough rewriting. New technologies had been developed and existing technologies had advanced, new theories and methodologies had emerged in the research literature, and my own understanding of automation and production systems had grown and matured (at least I think so). Readers of the two previous books will find this new volume to be quite different from its predecessors. Its organization is significantly changed, new topics have been added, and some topics from the previous editions have been discarded or reduced in coverage. It is not an exaggeration to say that the entire text has been rewritten (readers will find very few instances where I have used the same wording as in the previous editions). Nearly all of the figures are new. It is essentially a new book.

There is a risk in changing the book so much. Both of the previous editions have been very successful for Prentice Hall and me. Many instructors have adopted the book and have become accustomed to its organization and coverage. Many courses have been developed based on the book. What will these instructors think of the new edition, with all of its new and different features? My hope is that they will try out the new book and find it to be a significant improvement over the 1987 edition, as well as any other textbook on the subject.

Specifically, what are the changes in this new edition? To begin with, the organization has been substantially revised. Following two introductory chapters, the book is organized into five main parts:

I. **Automation and control technologies**: Six chapters on automation, industrial computer control, control system components, numerical control, industrial robotics, and programmable logic controllers.

II. **Material handling technologies**: Four chapters covering conventional and automated material handling systems (e.g., conveyor systems and automated guided vehicle systems), conventional and automated storage systems, and automatic identification and data capture.

III. **Manufacturing systems**: Seven chapters on a manufacturing systems taxonomy, single station cells, group technology, flexible manufacturing systems, manual assembly lines, transfer lines, and automated assembly.

IV. **Quality control systems**: Four chapters covering quality assurance, statistical process control, inspection principles, and inspection technologies (e.g., coordinate measuring machines and machine vision).

V. **Manufacturing support systems**: Four chapters on product design and CAD/CAM, process planning, production planning and control, and lean production and agile manufacturing.

Other changes in organization and coverage in the current edition, compared with the 1987 book, include:

- Expanded coverage of automation fundamentals, numerical control programming, group technology, flexible manufacturing systems, material handling and storage, quality control and inspection, inspection technologies, programmable logic controllers.
- New chapters or sections on manufacturing systems, single station manufacturing systems, mixed-model assembly line analysis, quality assurance and statistical process control, Taguchi methods, inspection principles and technologies, concurrent engineering, automatic identification and data collection, lean and agile manufacturing.
- Consolidation of numerical control into one chapter (the old edition had three chapters).
- Consolidation of industrial robotics into one chapter (the old edition had three chapters).
- The chapters on control systems have been completely revised to reflect current industry practice and technology.
- More quantitative problems on more topics: nearly 400 problems in the new edition, which is almost a 50% increase over the 1987 edition.
- Historical notes describing the development and historical background of many of the automation technologies.

With all of these changes and new features, the principle objective of the book remains the same. It is a textbook designed primarily for engineering students at the advanced undergraduate or beginning graduate levels. It has the characteristics of an engineering textbook: equations, example problems, diagrams, and end-of-chapter exercises. A ***Solutions Manual*** is available from Prentice Hall for instructors who adopt the book.

The book should also be useful for practicing engineers and managers who wish to learn about automation and production systems technologies in modern manufacturing. In several chapters, application guidelines are presented to help readers decide whether the particular technology may be appropriate for their operations.

Acknowledgments

Several people should be mentioned for their contributions to the current edition. I am grateful to the following: Prof. G. Srinivasan of the Indian Institute of Technology, Madras, India, for his thoughtful reviews of Chapters 15 and 16*; Prof. Kalyan Ghosh, Department of Mathematics and Industrial Engineering at Ecole Polytechnique in Montreal, Quebec, Canada, for his suggestions on topics for this new edition; Prof. Steve Goldman, Department of Philosophy here at Lehigh who reviewed Chapter 27 on lean and agile production, and Marcia Hamm Groover, who was very helpful in solving my computer problems for me (she is my "computer tutor" and my wife). I must also thank several graduate students here at Lehigh (past and present) who did some of the research for the book for me: David Aber, Jose Basto, Pongsak Dulyapraphant, Murat Erkoc, Peter Heugler, Charalambos Marangos, Brant Matthews, Jianbiao Pan, Hulya Sener, Steve Wang, and Tongquiang Wu. I am also grateful for the help and encouragement provided by several editors at Prentice Hall, namely Marcia Horton, Bill Stenquist, Laura Curless, and Scott Disanno. Finally, I am thankful to all of the instructors who adopted the two previous editions, thus making those books commercially successful so that Prentice Hall would allow me to prepare this new edition.

*Chapters 15 and 16 are concerned with group technology and flexible manufacturing systems, respectively. Prof. Srinivasan first read about these topics in my 1980 ***Automation, Production Systems, and Computer-Aided Manufacturing***, while he was a student. He became interested in these topics and went on to make these his principal research areas. Now he is a GT and FMS expert, and so I asked him to review these chapters for me, which he graciously agreed to do.

About The Author

Mikell P. Groover is Professor of Industrial and Manufacturing Systems Engineering at Lehigh University, where he also serves as Director of the Manufacturing Technology Laboratory. He holds the following degrees, all from Lehigh: B.A. (1961) in Arts and Science, B.S. (1962) in Mechanical Engineering, M.S. (1966) and Ph.D. (1969) in Industrial Engineering. He is a Registered Professional Engineer in Pennsylvania (since 1972). His industrial experience includes full–time employment at Eastman Kodak Company as a Manufacturing Engineer. Since joining Lehigh, he has done consulting, research, and project work for a number of industrial companies including Ingersoll–Rand, Air Products & Chemicals, Bethlehem Steel, and Hershey Foods.

His teaching and research areas include manufacturing processes, metal cutting theory, automation and robotics, production systems, material handling, facilities planning, and work systems. He has received a number of teaching awards, including the ***Albert Holzman Outstanding Educator Award*** from the Institute of Industrial Engineers (IIE). His publications include over 75 technical articles and papers which have appeared in ***Industrial Engineering***, ***IIE Transactions***, ***NAMRC Proceedings***, ***ASME Transactions***, ***IEEE Spectrum***, ***International Journal of Production Systems***, ***Encyclopaedia Britannica***, ***SME Technical Papers***, and others. Professor Groover's avocation is writing textbooks on topics in manufacturing and automation. His previous books are used throughout the world and have been translated into French, German, Korean, Spanish, Portuguese, Russian, Japanese, and Chinese. His book ***Fundamentals of Modern Manufacturing*** received the 1996 ***IIE Joint Publishers Award*** and the 1996 ***M. Eugene Merchant Manufacturing Textbook Award*** from the Society of Manufacturing Engineers.

Dr. Groover is a member of the Institute of Industrial Engineers, American Society of Mechanical Engineers (ASME), Society of Manufacturing Engineers (SME), and North American Manufacturing Research Institute (NAMRI). He is a Fellow of IIE and SME.

PREVIOUS BOOKS BY THE AUTHOR

Automation, Production Systems, and Computer-Aided Manufacturing, Prentice Hall, 1980.

CAD/CAM: Computer–Aided Design and Manufacturing, Prentice Hall, 1984 (co-authored with E. W. Zimmers, Jr.).

Industrial Robotics: Technology, Programming, and Applications, McGraw–Hill, 1986 (co-authored with M. Weiss, R. Nagel, and N. Odrey).

Automation, Production Systems, and Computer Integrated Manufacturing, Prentice Hall, 1987.

Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, Prentice Hall, 1996.

Contents

PART V: MANUFACTURING SUPPORT SYSTEMS

chapter 1

Introduction

CHAPTER CONTENTS

This book is about production systems that are used to manufacture products and the parts assembled into those products. The *production system* is the collection of people, equipment, and procedures organized to accomplish the manufacturing operations of a company (or other organization). Production systems can be divided into two categories or levels as indicated in Figure 1.1:

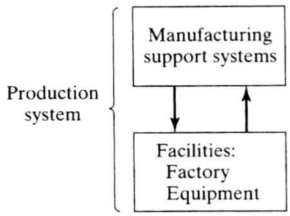

Figure 1.1 The production system consists of facilities and manufacturing support systems.

1. *Facilities.* The facilities of the production system consist of the factory, the equipment in the factory, and the way the equipment is organized.
2. *Manufacturing support systems.* This is the set of procedures used by the company to manage production and to solve the technical and logistics problems encountered in ordering materials, moving work through the factory, and ensuring that products meet quality standards. Product design and certain business functions are included among the manufacturing support systems.

In modern manufacturing operations, portions of the production system are automated and/or computerized. However, production systems include people. People make these systems work. In general, direct labor people *(blue collar workers)* are responsible for operating the facilities, and professional staff people *(white collar workers)* are responsible for the manufacturing support systems.

In this introductory chapter, we consider these two aspects of production systems and how they are sometimes automated and/or computerized in modern industrial practice. In Chapter 2, we examine the manufacturing operations that the production systems are intended to accomplish.

1.1 PRODUCTION SYSTEM FACILITIES[1]

The *facilities* in the production system are the factory, production machines and tooling, material handling equipment, inspection equipment, and the computer systems that control the manufacturing operations. Facilities also include the *plant layout*, which is the way the equipment is physically arranged in the factory. The equipment is usually organized into logical groupings, and we refer to these equipment arrangements and the workers who operate them as the *manufacturing systems* in the factory. Manufacturing systems can be individual work cells, consisting of a single production machine and worker assigned to that machine. We more commonly think of manufacturing systems as groups of machines and workers, for example, a production line. The manufacturing systems come in direct physical contact with the parts and/or assemblies being made. They "touch" the product.

A manufacturing company attempts to organize its facilities in the most efficient way to serve the particular mission of that plant. Over the years, certain types of production facilities have come to be recognized as the most appropriate way to organize for a given type of manufacturing. Of course, one of the most important factors that determine the type of manufacturing is the type of products that are made. Our book is concerned primarily with

[1] Portions of this section are based on M. P. Groover, *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* [2].

the production of discrete parts and products, compared with products that are in liquid or bulk form, such as chemicals (we examine the distinction in Section 2.1).

If we limit our discussion to discrete products, the quantity produced by a factory has a very significant influence on its facilities and the way manufacturing is organized. *Production quantity* refers to the number of units of a given part or product produced annually by the plant. The annual part or product quantities produced in a given factory can be classified into three ranges:

1. *Low production*: Quantities in the range of 1 to 100 units per year.
2. *Medium production*: Quantities in the range of 100 to 10,000 units annually.
3. *High production*: Production quantities are 10,000 to millions of units.

The boundaries between the three ranges are somewhat arbitrary (author's judgment). Depending on the types of products we are dealing with, these boundaries may shift by an order of magnitude or so.

Some plants produce a variety of different product types, each type being made in low or medium quantities. Other plants specialize in high production of only one product type. It is instructive to identify product variety as a parameter distinct from production quantity. *Product variety* refers to the different product designs or types that are produced in a plant. Different products have different shapes and sizes and styles; they perform different functions; they are sometimes intended for different markets; some have more components than others; and so forth. The number of different product types made each year can be counted. When the number of product types made in a factory is high, this indicates high product variety.

There is an inverse correlation between product variety and production quantity in terms of factory operations. When product variety is high, production quantity tends to be low; and vice versa. This relationship is depicted in Figure 1.2. Manufacturing plants tend to specialize in a combination of production quantity and product variety that lies somewhere inside the diagonal band in Figure 1.2. In general, a given factory tends to be limited to the product variety value that is correlated with that production quantity.

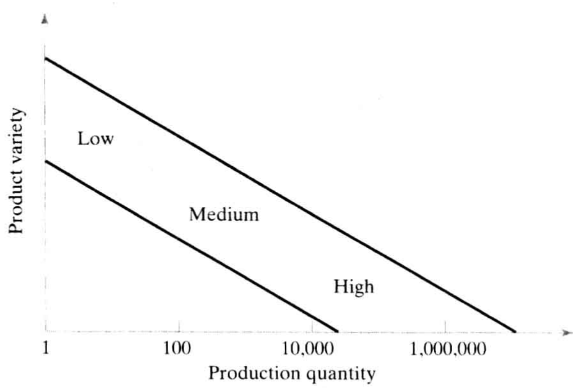

Figure 1.2 Relationship between product variety and production quantity in discrete product manufacturing.

Although we have identified product variety as a quantitative parameter (the number of different product types made by the plant or company), this parameter is much less exact than production quantity is, because details on how much the designs differ are not captured simply by the number of different designs. The differences between an automobile and an air conditioner are far greater than between an air conditioner and a heat pump. Products can be different, but the extent of the differences may be small or great. The automotive industry provides some examples to illustrate this point. Each of the U.S. automotive companies produces cars with two or three different nameplates in the same assembly plant, although the body styles and other design features are nearly the same. In different plants, the same auto company builds heavy trucks. Let us use the terms "hard" and "soft" to describe these differences in product variety. *Hard product variety* is when the products differ substantially. In an assembled product, hard variety is characterized by a low proportion of common parts among the products; in many cases, there are no common parts. The difference between a car and a truck is hard. *Soft product variety* is when there are only small differences between products, such as the differences between car models made on the same production line. There is a high proportion of common parts among assembled products whose variety is soft. The variety between different product categories tends to be hard; the variety between different models within the same product category tends to be soft.

We can use the three production quantity ranges to identify three basic categories of production plants. Although there are variations in the work organization within each category, usually depending on the amount of product variety, this is nevertheless a reasonable way to classify factories for the purpose of our discussion.

1.1.1 Low Quantity Production

The type of production facility usually associated with the quantity range of 1 to 100 units/year is the *job shop*, which makes low quantities of specialized and customized products. The products are typically complex, such as space capsules, aircraft, and special machinery. Job shop production can also include fabricating the component parts for the products. Customer orders for these kinds of items are often special, and repeat orders may never occur. Equipment in a job shop is general purpose and the labor force is highly skilled.

A job shop must be designed for maximum flexibility to deal with the wide part and product variations encountered (hard product variety). If the product is large and heavy, and therefore difficult to move in the factory, it typically remains in a single location, at least during its final assembly. Workers and processing equipment are brought to the product, rather than moving the product to the equipment. This type of layout is referred to as a *fixed–position layout*, shown in Figure 1.3(a). In the pure situation, the product remains in a single location during its entire fabrication. Examples of such products include ships, aircraft, railway locomotives, and heavy machinery. In actual practice, these items are usually built in large modules at single locations, and then the completed modules are brought together for final assembly using large-capacity cranes.

The individual parts that comprise these large products are often made in factories that have a *process layout*, in which the equipment is arranged according to function or type. The lathes are in one department, the milling machines are in another department, and so on, as in Figure 1.3(b). Different parts, each requiring a different operation sequence,

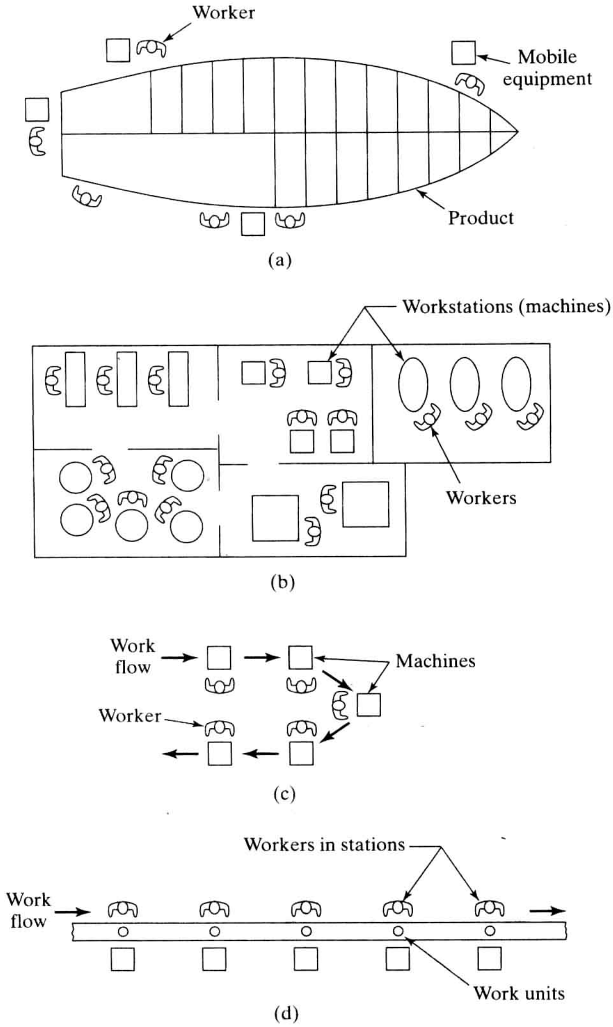

Figure 1.3 Various types of plant layout: (a) fixed-position layout, (b) process layout, (c) cellular layout, and (d) product layout.

are routed through the departments in the particular order needed for their processing, usually in batches. The process layout is noted for its flexibility; it can accommodate a great variety of alternative operation sequences for different part configurations. Its disadvantage is that the machinery and methods to produce a part are not designed for high efficiency. Much material handling is required to move parts between departments, so in-process inventory can be high.