FLEXIBLE MANUFACTURING SYSTEMS

CURRENT ISSUES

AND MODELS

Edited By
Fred Choobineh
and Rajan Suri

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Published by:
Industrial Engineering and Management Press
Institute of Industrial Engineers

Industrial Engineering and Management Press, 25 Technology Park/Atlanta,
Norcross, Georgia 30092 404/449-0460

© 1986 by the Institute of Industrial Engineers

Published 1986
Printed in the United States of America

ISBN 0-89806-078-8

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PREFACE

Recently, Flexible Manufacturing System (FMS) has been in the limelight of manufacturing system technology. For the enthusiast who is interested in learning about all the issues surrounding this technology, however, no textbooks or structured reading materials are on the market. With this volume, we have attempted to fill this vacuum.

Flexible Manufacturing Systems: Current Issues and Models is intended for manufacturing managers and engineers who currently operate or plan to acquire an FMS. We are convinced that each of these groups would stand to benefit from the knowledge of issues addressed in this book. Also, this volume is structured for use as a suitable textbook for students in engineering and business.

Of course, our research, teaching, and consulting activities have influenced our views on what an FMS is, and what issues are pertinent to its successful design and implementation. A great amount of attention was devoted to selecting the articles, so that only well-written, nonesoteric articles with practical value would be included. This volume thus provides a comprehensive and structured coverage of issues central to an FMS.

The volume is divided into five sections. The first is intended to focus on the broad view of factory automation, and sets the stage for discussion of the issues. The second section focuses on the issues that arise in the initial planning, and subsequent design, of FMSs. Also presented are modelling methods appropriate in dealing with those issues. In the third section, issues related to the operation and control of FMSs are discussed. The fourth and fifth sections are more management oriented: the fourth deals with project planning and justification issues, and the fifth presents an overview of some of the existing systems, and perspectives from users and vendors on the present status and future direction of FMS technology.

Materials that we thought may appeal to a smaller group of enthusiasts have been placed in three appendices. The first gives a very brief overview of Local Area Networks (LANs) and MAP. The second appendix contains the complete listing of a simulation model of a hypothetical FMS, which has been coded in the GPSS/H simulation language as an example. The third appendix is an up-to-date bibliography of approximately 200 articles and books related to FMS. We do not claim that the bibliography is comprehensive; however, it contains most of the pertinent articles currently available. This appendix should be especially valuable to those readers who are interested in conducting FMS-related research.

Fred Choobineh
University of Nebraska-Lincoln

Rajan Suri
University of Wisconsin-Madison

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INTRODUCTION TO AUTOMATION AND ITS COMPONENTS

In an unmanned factory, computers are programmed to operate the machine tools, material handling systems, and inspection devices involved in parts manufacturing; human operators are not required on the factory floor. An unmanned factory may consist of one or more FMSs, or groups of machine tools which are dedicated to the manufacture of a part family and all the machine tools and material handling systems are under control of a computer system. Thus, an FMS can be viewed as a building block of an unmanned factory. Understanding the issues related to an FMS facilitates the design and operation of an unmanned factory.

We believe that a prerequisite to understanding the issues related to an FMS is a firm grasp of concepts behind the family of technologies employed by an FMS. The first article of this section was selected to provide the necessary overview of the technology.

An edited version of a chapter within a report prepared by the U.S. Congress Office of Technology Assessment on Computerized Manufacturing Automation opens our volume. The unedited version of the chapter describes the technology that makes the vision of an unmanned factory possible. Because of space limitations, we were unable to include the chapter in its entirety; the extracts, therefore, highlight the issues that are central to understanding FMSs. This article also provides a sense of where an FMS fits in the broad picture of factory automation.

In the second article, we offer a concise definition of an FMS: a programmable manufacturing cell. Also, the article sheds light on the meaning of flexibility in manufacturing, and reviews group technology that is essential to the design of a manufacturing cell.

An overview of an FMS is presented in the third article, which briefly describes the three primary components of an FMS, namely, machine tools, material handling systems, and supervisory computer control network. Computers exercise their control through a communication network referred to as Local Area Network (LAN). Appendix A gives a brief overview of LAN.

Programmable Automation Technologies

[EDITOR'S NOTE: This chapter contains edited extracts from a U.S. Government report.† The extracts consist of those parts of the chapter that are closely related to flexible manufacturing systems. The aim of this chapter is to define programmable automation (PA) in general and then set the context for FMS, which is primarily discrete manufacturing. The components of FMS are described and issues raised by this new technology are discussed. This chapter sets the stage for many of the detailed discussions that follow in the rest of the volume.]

Introduction

The purpose of this chapter is to describe the technologies that together comprise "programmable automation," and to evaluate their usefulness for manufacturing. In addition, the chapter examines how the technologies are evolving and what can be expected for the capabilities and applications of these tools.

Programmable automation refers to a family of technologies that lie at the intersection of computer science and manufacturing engineering. "Programmable" means that they can be switched from one task to another with relative ease by changing the (usually) computerized instructions; "automation" implies that they perform a significant part of their functions without direct human intervention. The common element in these tools that makes them different from traditional manufacturing tools is their use of the computer to manipulate and store data, and the use of related microelectronics technology to allow communication of data to other machines in the factory.*

There are three general categories of functions which these tools perform—they are used to help design products, to help manufacture (both fabricate and assemble) products on the factory floor, and to assist in management of many factory operations. Table 5 outlines the principal technologies included in these categories, each of which will be described in the next section.

*Although "programmable automation" is less common than some of the other terms used to describe automation technologies, it is a relatively simple and unambiguous term for the tools discussed here. "CAD/CAM" (computer-aided design/computer-aided manufacturing) is a catch-all term used in industry journals and popular articles to refer to a set of technologies similar to the set defined here as programmable automation. However, CAD/CAM is also used to describe some specific computer-aided design systems, or to denote the integration of computer-aided design and manufacturing. Because of this ambiguity, the term will not be used here. "Robotics" is another term that is sometimes used in a broad sense to mean not only robots but the whole family of automation tools.

†*Computerized Manufacturing Automation: Employment, Education, and the Workplace*, U.S. Congress, Office of Technology Assessment, Report OTA-CIT-235, Washington, D.C., April 1984.

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Table 5.—Principal Programmable Automation Technologies

I. Computer-aided design (CAD)
  A. Computer-aided drafting
  B. Computer-aided engineering (CAE)

II. Computer-aided manufacturing (CAM)
  A. Robots
  B. Numerically controlled (NC) machine tools
  C. Flexible manufacturing systems (FMS)
  D. Automated materials handling (AMH) and automated storage and retrieval systems (AS/RS)

III. Tools and strategies for manufacturing management
  A. Computer-integrated manufacturing (CIM)
  B. Management information systems (MIS)
  C. Computer-aided planning (CAP) and computer-aided process planning (CAPP)

NOTE: Bold type indicates technologies on which this report concentrates.
SOURCE: Office of Technology Assessment.

The three categories of automation technologies—tools for design, manufacturing, and management—are not mutually exclusive. In fact, the goal of much current research in automation systems is to break down the barriers between them so that design and manufacturing systems are inextricably linked. However, these three categories are useful to frame the discussion, particularly since they correspond to the organization of a typical manufacturing firm.

Further, this report does not attempt to cover each of the technologies in equal detail. It concentrates on those five which appear in bold type in table 5 because they are the core technologies of PA and their potential uses are most extensive.

Discrete Manufacturing

Some background about manufacturing is important to provide a context for assessing the usefulness of these tools. Programmable automation can affect many kinds of industry. This report focuses on PA† applications for discrete manufacturing—the design, manufacture and assembly of products ranging from bolts to aircraft. The report does not systematically cover nonmanufacturing applications such as architecture, or continuous-process manufacturing—e.g., chemicals, paper, and steel. Other recent OTA reports have examined technological changes affecting process industries.[1]

Electronics manufacturing industries do not fit neatly into a discrete v. process classification. Some areas, particularly the fabrication of semiconductors, most resemble continuous-process manufacturing. Other portions such as circuit board assembly are more discrete. Because electronics industries have been leaders among metalworking firms in both producing and using computerized factory automation, they play a key role in this report.

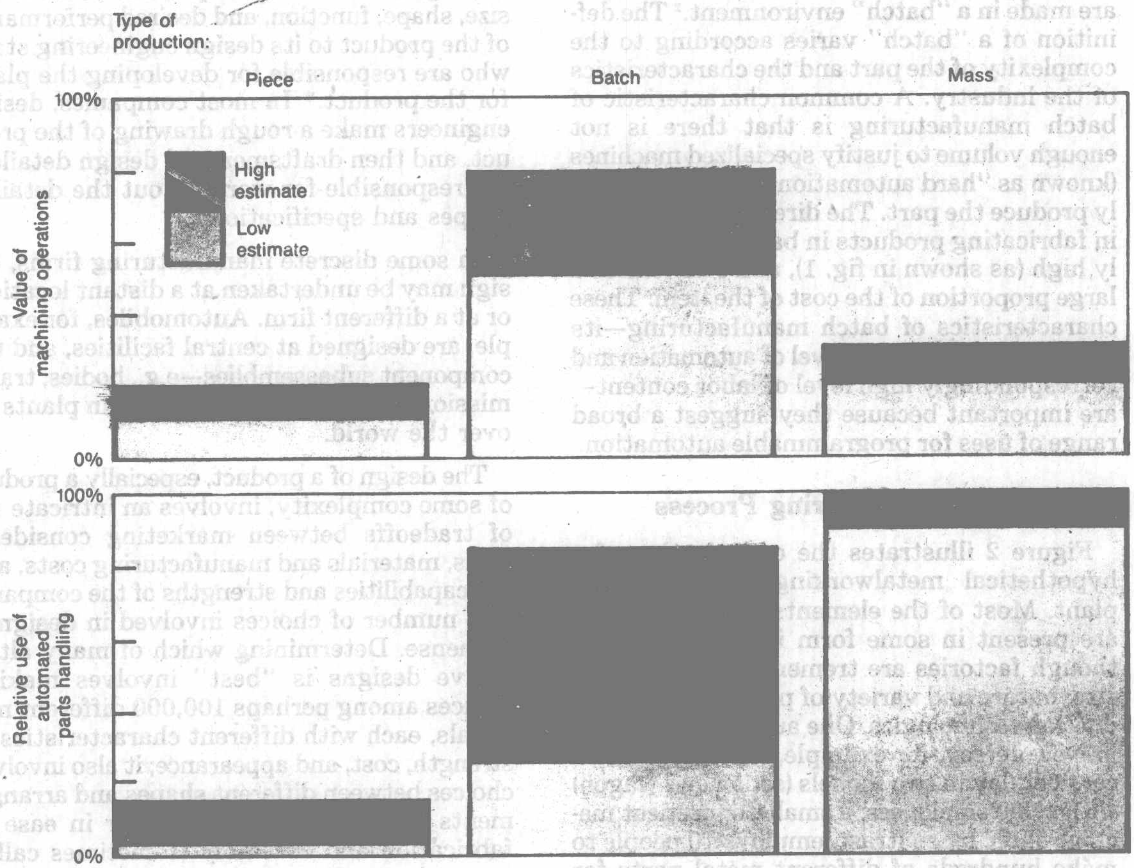
To many industrialists, discrete manufacturing means metalworking for mechanical applications—shaping, forming, and finishing metals into usable products such as engine blocks. However, an increasing proportion of mechanical parts manufacturing involves plastics, fiber composites, or new, durable ceramics. These new materials both enable new production processes and are themselves affected by automation technologies.

One way in which discrete manufacturing plants can be categorized that is especially relevant to automation applications is the volume of a given part that they produce. As figure 1 indicates, discrete manufacturing represents a continuum from piece or custom production of a single part to mass production of many thousands. Although many people are most familiar with mass-production factories, with their assembly and transfer lines, it is estimated that mass production accounts for only 20 percent of metalworking parts pro-

[1]Cf. *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-ISC-135, July 1982); *Technology and Steel Industry Competitiveness* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-M-122, June 1980).

† *Programmable Automation*

Figure 1.—Characteristics of Metalworking Production, By Lot Size



		Piece	Batch	Mass
Typical lot size	Large complex part	1-10	10-300	Over 200
	Small simple part	1-300	300-15,000	Over 10,000
Typical products		Aircraft, large turbines, centrifuges	Marine engines, large electric motors, tractors	Autos, fasteners, small appliances
Typical machines		Manual machine tools, or stand-alone numerically controlled (NC) machine tools	NC machine tools with automated part-handling machining cell flexible manufacturing system	Transfer lines, dedicated or special machines

SOURCE: Machine Tool Task Force, *Technology of Machine Tools*, October 1980.

duced in the United States, while 75 percent are made in a "batch" environment.[2] The definition of a "batch" varies according to the complexity of the part and the characteristics of the industry. A common characteristic of batch manufacturing is that there is not enough volume to justify specialized machines (known as "hard automation") to automatically produce the part. The direct labor involved in fabricating products in batches is relatively high (as shown in fig. 1), and constitutes a large proportion of the cost of the item. These characteristics of batch manufacturing—its prevalence, and its low level of automation and correspondingly high level of labor content—are important because they suggest a broad range of uses for programmable automation.

The Manufacturing Process

Figure 2 illustrates the organization of a hypothetical metalworking manufacturing plant. Most of the elements in this diagram are present in some form in each plant, although factories are tremendously varied in size, nature and variety of products, and production technologies. One automobile factory in New Jersey, for example, assembles 1,000 cars per day in two models (sedan and wagon) with 4,000 employees; a small Connecticut machine shop, by contrast, employs 10 people to make hundreds of different metal parts for aircraft and medical equipment, typically in batches of approximately 250.[3]

As illustrated in figure 3, the manufacturing process usually begins when management decides to make a new product based on information from its marketing staff, or (in the case of the many factories which produce parts of other companies' products) management receives a contract to produce a certain part. Management sends the specifications for the size, shape, function, and desired performance of the product to its design engineering staff, who are responsible for developing the plans for the product.* In most companies, design engineers make a rough drawing of the product, and then draftsmen and design detailers are responsible for working out the detailed shapes and specifications.

In some discrete manufacturing firms, design may be undertaken at a distant location, or at a different firm. Automobiles, for example, are designed at central facilities, and the component subassemblies—e.g., bodies, transmissions, engines—are produced in plants all over the world.

The design of a product, especially a product of some complexity, involves an intricate set of tradeoffs between marketing considerations, materials and manufacturing costs, and the capabilities and strengths of the company. The number of choices involved in design is immense. Determining which of many alternative designs is "best" involves making choices among perhaps 100,000 different materials, each with different characteristics of strength, cost, and appearance; it also involves choices between different shapes and arrangements of parts which will differ in ease of fabrication and assembly (sometimes called "manufacturability") and in performance.

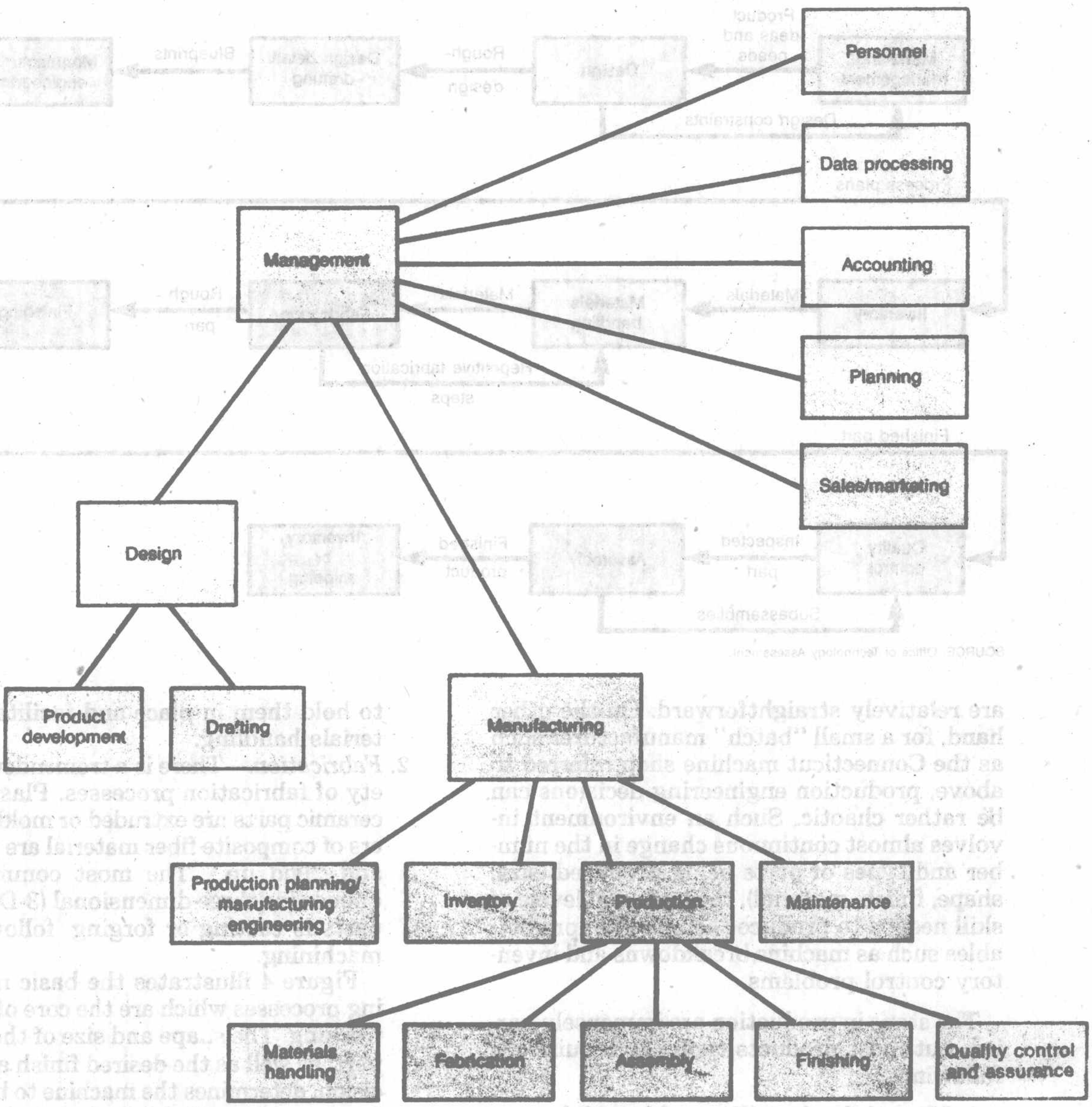
From the design, the production engineering staff determines the "process plan"—machines, staff, and materials which will be used to make the product. Production planning, like design, involves a set of complex choices. In a mass production plant that manufactures only a few products, such as the auto plant described above, production engineering is a relatively well-structured problem. With high volumes and fairly reliable expectations about the products to be made, decisions about appropriate levels of automation, for example,

[2] M. E. Merchant, "The Inexorable Push for Automated Production," *Production Engineering*, January 1977, pp. 44-49. This 75 percent figure has become something of a legend in the metalworking industry largely through Merchant's writings, though he notes that he has lost track of the original reference for the statistic. While it is hard to substantiate given the diversity of metalworking industry, Merchant and other industry experts cite it as a good rough estimate. Personal communication, M. E. Merchant, No[illegible], 1983.

[3] OTA work environment case studies.

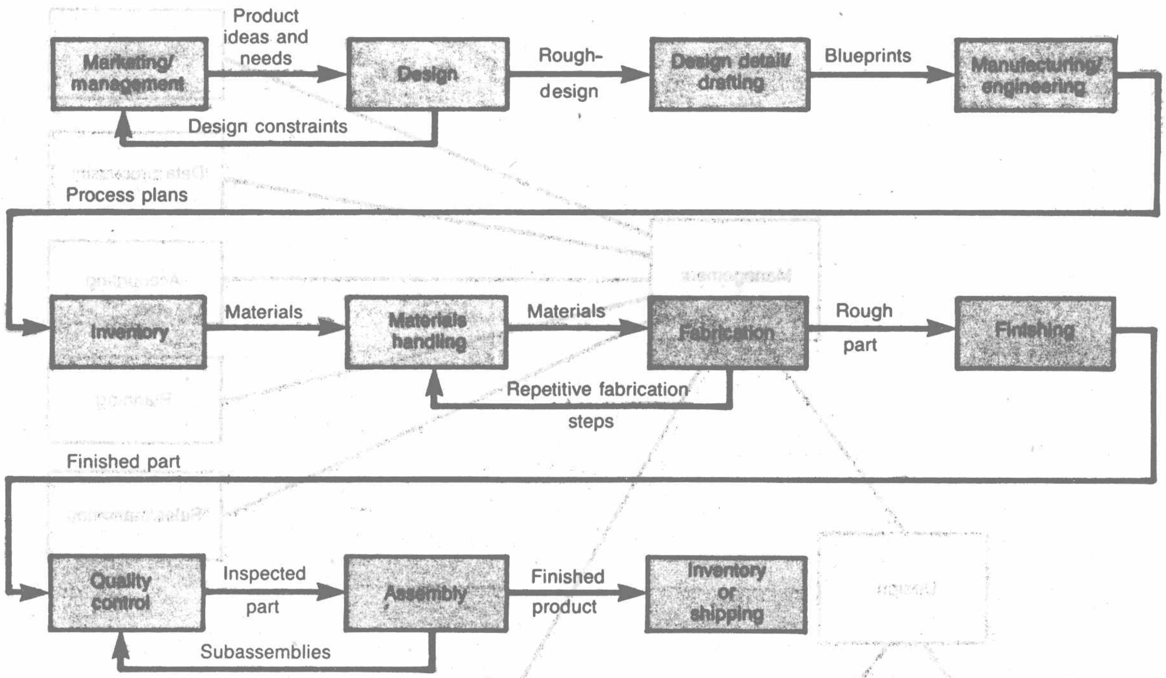
*In this description, as in the rest of the chapter, titles such as "manager," "design engineer," or "draftsman" indicate the person who performs these functions. In an actual company the roles may be less distinct, and boundaries between them frequently changing.

Figure 2.—Organizational Diagram of a Manufacturing Firm



SOURCE: Office of Technology Assessment.

Figure 3.—Steps in the Manufacturing Process (Simplified)



SOURCE: Office of Technology Assessment.

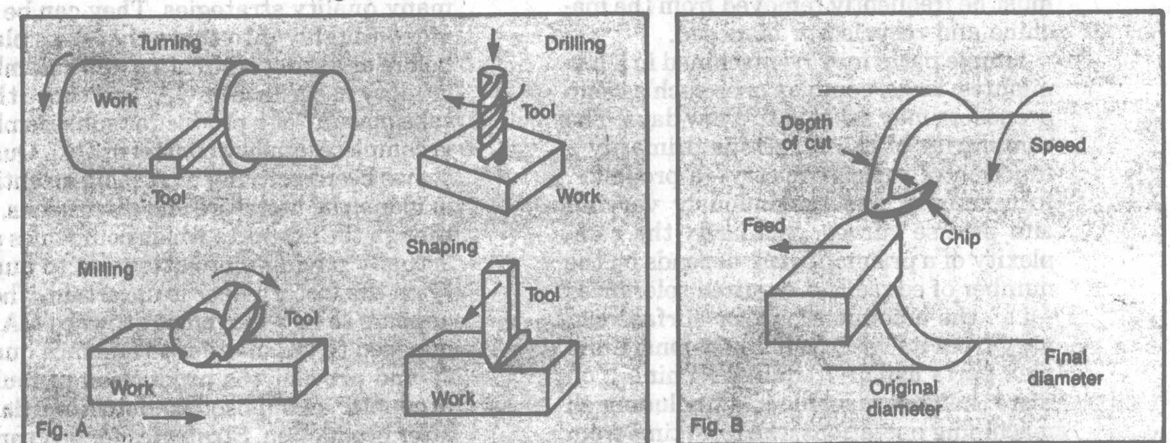
are relatively straightforward. On the other hand, for a small "batch" manufacturer such as the Connecticut machine shop referred to above, production engineering decisions can be rather chaotic. Such an environment involves almost continuous change in the number and types of parts being produced (size, shape, finish, material), the tools and levels of skill needed to produce them, and unpredictables such as machine breakdowns and inventory control problems.

The steps in production are immensely varied, but most products typically require the following:

1. *Materials handling.*—Materials are brought from inventory to processing stations, and from one station to another. Wheeled carts, forklift trucks, or conveyors are typically used for this purpose. Early in the production process, large parts are mounted on a pallet or fixture to hold them in place and facilitate materials handling.
2. *Fabrication.*—There is a tremendous variety of fabrication processes. Plastic and ceramic parts are extruded or molded; layers of composite fiber material are treated and "laid up." The most common sequence for three-dimensional (3-D) metal parts is casting or forging, followed by machining.

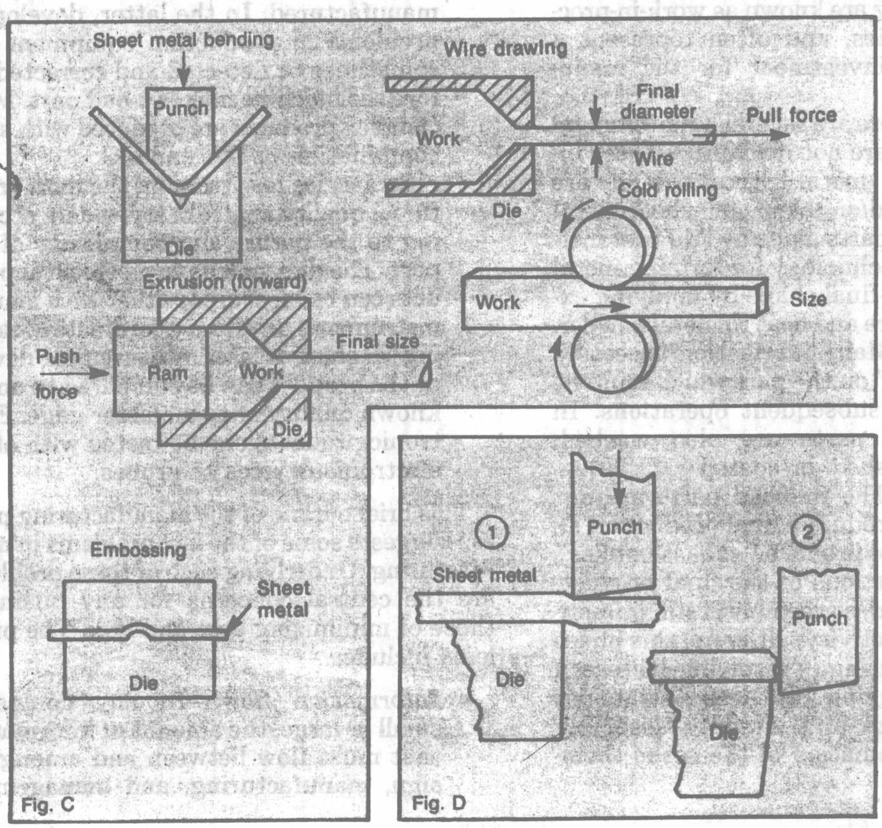
Figure 4 illustrates the basic machining processes which are the core of metalworking. The shape and size of the metal part, as well as the desired finish and precision, determines the machine to be used. Some machine tools, such as lathes, are designed for cylindrical parts, e.g., drive shafts or rotors. Others, such as planers, are designed for prismatic parts with basically flat outer surfaces, e.g., engine blocks. Abrasive cutting of metal produces "chips," the metal shavings re-

Figure 4.—Fundamental Operations in Metalworking



[A] The four basic machining processes can, between them, theoretically produce any contour on a workpiece. Although the processes are old, they are the foundation of metalworking and are being made more productive and accurate.

[B] In any of the basic machining processes, speed, feed, and depth of cut determine productivity. The three variables are shown here for turning on a lathe.



[C] Forming operations bend, squeeze, or stretch metal, imparting new sizes or shapes, or both.

[D] Shearing deforms metal beyond its breaking point, thereby separating one portion of a metal sheet from another.

SOURCE: M. P. Groover, "Fundamental Operations," *IEEE Spectrum*, vol. 20, No. 5, May 1983. Reprinted with permission of *IEEE Spectrum*. ©IEEE.

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