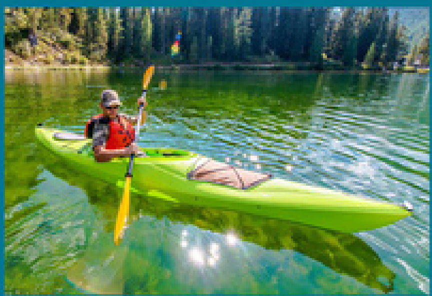
DeGarmo's Materials and Processes in Manufacturing

J T. Black ▪ Ronald A. Kohser

Thirteenth Edition



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13th Edition

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Preface

It's a world of manufactured goods. Whether we like it or not, we all live in a technological society. Every day we come in contact with hundreds of manufactured items, made from every possible material. From the bedroom to the kitchen to the workplace, we use appliances, phones, cars, trains, and planes, TVs, cell phones, VCRs, DVDs, furniture, clothing, sports equipment, books and more. These goods are manufactured in factories all over the world using manufacturing processes.

Basically, manufacturing is a value-adding activity, where the conversion of materials into products adds value to the original material. Thus, the objective of a company engaged in manufacturing is to add value and to do so in the most efficient manner, with the least amount of waste in terms of time, material, money, space, and labor. To minimize waste and increase productivity, the processes and operations need to be properly selected and arranged to permit smooth and controlled flow of material through the factory and provide for product variety. Meeting these goals requires an engineer who can design and operate an efficient manufacturing system. Here are some trends that are having impacts on the manufacturing world.

- **Manufacturing is a global activity**

  Manufacturing is a global activity with work often being performed at locations based on proximity to materials, labor, or marketplace. US firms often have plants in other countries, and foreign companies operate plants in the United States. Final product assembly often involves components made at a variety of locations.

- **It's a digital world**

  Information technology and computers are growing exponentially, with usage in virtually every aspect of manufacturing. Design and material selection are performed on computers, and this information is then transmitted to manufacture, where machines are often operated and controlled by computers. Computerized inspection processes ensure product quality.

- **Lean manufacturing is widely practiced**

  Most manufacturing companies have restructured their factories (their manufacturing systems) to become lean producers—making goods of superior quality, cheaper and faster, in a flexible way (i.e., they are more responsive to the customers). Almost every plant is doing something to become leaner. Many have adopted some version of the Toyota Production System. More importantly, these manufacturing factories are also designed with the internal customer (the workforce) in mind, so things such as ergonomics and safety are key design requirements. While this book is all about materials and processes for making products, the design of the factory cannot be ignored when it comes to making the external customer happy with the product and the internal customer satisfied with the employer.

- **New products and materials need new processes**

  The number and variety of products and the materials from which they are made continues to proliferate, while production quantities (lot sizes) have become smaller. Existing processes must be modified to be more flexible, and new processes must be developed.

- **Customers expect great quality**

  Consumers want better quality and reliability, so the methods, processes, and people responsible for that quality must improve continually. Reducing the number and magnitude of flaws and defects often requires continual changes to the manufacturing system.

- **Rapid product development is required**

  Being competitive often requires reducing the time to market for new products. Many companies are taking holistic or systemwide perspectives, including concurrent engineering efforts to bring product design and manufacturing closer to the customer. Products are being designed to be easier to manufacture and assemble (design for manufacture/assembly). Manufacturing systems are becoming more flexible (able to rapidly adapt to and assimilate new products).

- **3-D printing and additive manufacturing is exploding**

  New and improved processes, new materials, and expanded capability machines and equipment are entering the market on an almost weekly basis. Technology that once produced lookalike prototype parts is now producing fully functional products from the full range of materials, including metals, ceramics, polymers, and biomaterials.

History of the Text

E. Paul DeGarmo was a mechanical engineering professor at the University of California, Berkley, when he wrote the first edition of *Materials and Processes in Manufacturing*, published by Macmillan in 1957. The book quickly became the emulated standard for introductory texts in manufacturing. Second, third, and fourth editions followed in 1962, 1969, and 1974. DeGarmo began teaching at Berkeley in 1937, after earning his master's of science degree in mechanical engineering from California Institute of Technology. He was a founder of the Department of Industrial Engineering (now Industrial Engineering and Operations Research) and served as its chairman from 1956–1960. He was also assistant dean of the College of Engineering for three years while continuing his teaching responsibilities.

Paul DeGarmo observed that engineering education had begun to place more emphasis on the underlying sciences at the expense of hands-on experience. Most of his students were coming to college with little familiarity with materials, machine tools, and manufacturing methods that their predecessors had acquired through their former "shop" classes. If these engineers and technicians were to successfully convert their ideas into reality, they needed a foundation in materials and processes, with emphasis on capabilities and limitations. Paul sought to provide a text that could be used in either a one- or two-semester course designed to meet these objectives. The materials sections were written with an emphasis on use and application. Processes and machine tools were described in terms of how they worked, what they could do, and their relative advantages and limitations, including economic considerations. The text was written for students who would be encountering the material for the first time, providing clear descriptions and numerous visual illustrations.

Paul's efforts were well-received, and the book quickly became the standard text in many schools and curricula. As materials and processes evolved, the advances were incorporated into subsequent editions. Computer usage, quality control, and automation were added to the text, along with other topics, so that it continued to provide state-of-the-art instruction in both materials and processes. As competing books entered the market, their subject material and organization tended to mimic the DeGarmo text.

Paul DeGarmo retired from active teaching in 1971, but he continued his research, writing, and consulting for many years. In 1977, after the publication of the fourth edition of *Materials and Processes in Manufacturing*, he received a letter from Ron Kohser, then an assistant professor at the University of Missouri-Rolla, containing numerous suggestions regarding the materials chapters. Paul DeGarmo asked Dr. Kohser to rewrite those chapters for the upcoming fifth edition. After that edition, Paul decided he was really going to retire and, after a national search, recruited J T. Black, then a professor at Ohio State, to co-author the book with Dr. Kohser.

For the sixth through 12th editions (published in 1984 and 1988 by Macmillan, 1997 by Prentice Hall, and 2003, 2008 and 2012 by John Wiley & Sons), Dr. Kohser and Dr. Black have shared the responsibility for the text. The chapters about engineering materials, casting, forming, powder metallurgy, additive manufacturing, joining and nondestructive testing have been written or revised by Dr. Kohser. Dr. Black has responsibility for the introduction and chapters about material removal, metrology, surface finishing, quality control, manufacturing systems design, and lean engineering.

Paul DeGarmo died in 2000, three weeks short of his 93rd birthday. For the 10th edition, which coincided with the 50th anniversary of the text, Dr. Black and Dr. Kohser honored their mentor with a change in the title to include his name—*DeGarmo's Materials and Processes in Manufacturing*. We recognize Paul DeGarmo for his insight and leadership and are forever indebted to him for selecting us to carry on the tradition of his book for this, the 13th edition.

Purpose of the Book

The purpose of this book is to provide basic information on materials, manufacturing processes and systems to students of engineering and technology. The materials section focuses on properties and behavior. Aspects of smelting, refining, or other material production processes are presented only as they affect subsequent use and application. In terms of the processes used to manufacture items (converting materials into useful shapes with desired properties), this text seeks to provide a descriptive introduction to a wide variety of options, emphasizing how each process works and its relative advantages and limitations. The goal is to present this material in a way that can be understood by individuals seeing it for the very first time. This is not a graduate text where the objective is to thoroughly understand and optimize manufacturing processes. Mathematical models and analytical equations are used only when they enhance the basic understanding of the material. Although the text is introductory in nature, new and emerging technologies, such as direct-digital and micro- and nano-manufacturing processes, are included as they transition into manufacturing usage.

Organization of the Book

E. Paul DeGarmo wanted a book that explained to engineers how the things they designed could be made. *DeGarmo's Materials and Processes in Manufacturing* is still being written to provide a broad, basic introduction to the fundamentals of manufacturing. The text begins with a survey of engineering materials, the "stuff" that manufacturing begins with, and seeks to provide the basic information that could be used to match the properties of a material to the service requirements of a component. A variety of engineering materials are presented, along with their properties and means of modifying them. The materials section can be used in curricula that lack preparatory courses in metallurgy, materials science, or strength of materials, or where the student has not yet been exposed to those topics. In addition, various chapters in this section can be used as supplements to a basic materials course, providing additional information about topics such as heat treatment, plastics, composites, and material selection.

Following the materials chapters are sections about casting, powder metallurgy, forming, material removal, and joining. Each section begins with a presentation of the fundamentals on which those processes are based. These introductions are followed by a discussion about the various process alternatives, which can be selected to operate individually or be combined into an integrated system.

Reflecting the many recent developments and extreme interest in additive manufacturing (often called 3-D printing), the chapter about this technology has been significantly updated to present the various technologies in place at the time of textbook printing. Uses and applications are summarized, including prototype manufacture, rapid tooling, and direct-digital manufacture. The advantages and limitations of additive manufacturing are summarized, along with a description of current and future trends.

Manufacturing processes are often designed to accommodate specific materials. A separate chapter presents those processes that are somewhat unique to plastics, ceramics, and composites.

Chapters have been included to provide information about surface engineering, measurements, nondestructive testing, and quality control. Engineers need to know how to determine process capability and, if they get involved in Six Sigma projects, to know what sigma really measures. There is also introductory material about surface integrity, since so many processes produce the finished surface and impart residual stresses to the components.

Many of the advances in manufacturing relate to the way the various processes are implemented and integrated in a production plant or on the shop floor—the design of manufacturing systems. Aspects of automation, numerical control, and robotics are presented in a separate chapter. In addition, there is expanded coverage of lean engineering, in which the mass production system is converted into a lean production system, capable of rapidly manufacturing variations of a product, small quantities of a product, or even one-of-a-kind items on a very flexible and continual basis.

With each new edition, new and emerging technology is incorporated, and existing technologies are updated to accurately reflect current capabilities. Through its 60-year history and 12 previous editions, the DeGarmo text was often the first introductory book to incorporate processes such as friction-stir welding, microwave heating and sintering, and machining dynamics.

This 13th edition is published as an enhanced eText. Each chapter includes review questions that allow the student to check their understanding. A number of these questions include answers the student can access with a click or tap. The *Problems* section further applies this understanding, with a bit of focus on application, including a selection of new problems added for this edition. An increased number of somewhat open-ended case studies also are provided in the eText. These have been designed to make students aware of the great importance of properly integrating design, material selection, and manufacturing to produce cost-competitive, reliable products.

The DeGarmo text is intended for use by engineering (mechanical, lean, manufacturing, industrial, and materials) and engineering technology students, in both two- and four-year undergraduate degree programs. In addition, the book is also used by engineers and technologists in other disciplines concerned with design and manufacturing (such as aerospace and electronics). Factory personnel find this book to be a valuable reference that concisely presents the various production alternatives and the advantages and limitations of each. Additional or more in-depth information about specific materials or processes can be found in an expanded list of supplemental references that is organized by topic.

Supplements

An instructor solutions manual for instructors adopting the text for use in their courses is available on a companion website: www.wiley.com/go/black/degarmomaterials13E. Additional student practice questions also are available from the companion site.

Acknowledgments

The authors wish to acknowledge the multitude of assistance, information, and illustrations that have been provided by a variety of industries, professional organizations, and trade associations. The text has become known for the large number of clear and helpful photos and illustrations that have been provided graciously by a variety of sources. In some cases, equipment is photographed or depicted without safety guards, so as to show important details, and personnel are not wearing certain items of safety apparel that would be worn during normal operation.

Over the many editions, hundreds of reviewers, user faculty, and students have submitted suggestions and corrections to the text. We continue to be grateful for their input.

The authors also would like to acknowledge the contributions of Dr. Elliot Stern for the dynamics of machining section in Chapter 21, Dr. Brian Paul for writing the micro-manufacturing chapter, Dr. Kavit Antani for his contributions in lean engineering and system design, Dr. Andres Carrano for his work in measurements/metrology, Prof. Julia Morse for her contributions to NC and CNC, and Mr. Kevin Slattery of the Boeing Company for his review of the chapter on additive manufacturing.

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The authors also thank the John Wiley & Sons team that worked on the book, including Padmapriya Soundararajan, Judy Howarth and Chris Nelson.

About the Authors

J T. Black received his PhD from Mechanical and Industrial Engineering, University of Illinois, Urbana, in 1969, a master's of science degree in industrial engineering from West Virginia University in 1963, and his bachelor of science degree in industrial engineering, Lehigh University, in 1960. J T. is professor emeritus from Industrial and Systems Engineering at Auburn University. He was the chairman and a professor of Industrial and Systems Engineering at University of Alabama-Huntsville. He also taught at Ohio State University, University of Rhode Island, University of Vermont, and University of Illinois. He taught his first processes class in 1960 at West Virginia University. J T. is a Fellow in the American Society of Mechanical Engineers, the Institute of Industrial Engineering and the Society of Manufacturing Engineers. J loves to write music (mostly down-home country) and poetry, play tennis in the backyard, and show his champion pug dogs.

Ron Kohser received his PhD from Lehigh University Institute for Metal Forming in 1975. He then joined the faculty of the University of Missouri-Rolla, now the Missouri University of Science & Technology, where he held positions of professor of metallurgical engineering, dean's teaching scholar, department chairman and associate dean for undergraduate instruction. Ron consistently carried a full teaching load, including metallurgy for engineers; introduction to manufacturing processes; material selection, fabrication, and failure analysis; materials processing; powder metallurgy; and metal deformation processes. In 2013, he retired as professor emeritus, and moved to the Lake of the Ozarks, where he and his wife helped build their retirement home.

About the Cover

The four boats on the cover are a one-person kayak, a family cruiser, a racing-type speed boat, and a large cruise ship. While all are types of boats, and share some common functions, they also represent a spectrum of manufacturing and operating conditions that are often addressed through different “materials” and “processes”.

Light weight is a very desirable property of a kayak since it is usually transported by vehicle or by hand to and from the location of use. Durability is also required, especially if the use includes white water where impacts with rocks are likely to be encountered. Because the size is rather small, a single-piece hull is typical, eliminating the need for any form of joint. Power is provided entirely by the individual or the flow of moving water.

Family cruisers are available in a range of styles and sizes, with some even having kitchens, bathrooms, and sleeping quarters. As a consumer product, these types of boats must appeal to the buyer by providing the desired features at an acceptable price. Appearance is certainly an issue. Power may be provided through either inboard or outboard motors, typically of several hundred horsepower, and the hulls must be sufficiently durable to withstand impacts with various types of floating debris.

The objective of the racing boat is speed, and this drives both design and materials. Light weight will enable the boat to skim across the surface of the water without creating the added drag of water displacement. The immense power, often over a thousand horsepower, requires both strength and rigidity.

The large cruise ship is quite a contrast in almost every area. It is a floating hotel, complete with accompanying shops, restaurants, and entertainment and recreational opportunities. Its size requires the fabrication of a welded hull. Immense power is required not only for propulsion, but also operation of generators that power utilities and the various amenities throughout the ship.

Considering these four vessels, there is a significant variation in production quantities. The kayak is more of a mass-produced product, with many sharing identical features. The cruiser would be produced in smaller quantities, with variations available to suit the individual buyer. Racing boats are often hand crafted by teams of individuals, often with features unique to a given boat or type of competition. The cruise ship would be fabricated one at a time by a large group of specialists. Because of the variation in style and quantity, different types of tooling and degrees of automation would be employed. Corrosion resistance might not be an issue with a kayak, but would certainly be a consideration when the larger boats are used in a salt water environment.

Many of the materials and processes described in this book find themselves employed in one or more of the four cover boats. Each of the material-process combinations would have been selected because it offered the best match to the needs of the specific product and component. However, as new materials and processes are developed, the “best” solutions may constantly be changing. We invite the reader to open the text and explore this fascinating area of engineering and technology.

Contents

OC **Content available in eBook**
SS **Student solution available in interactive e-text**

Acronyms

AC	Adaptive Control
AFM	Abrasive Flow Machining
AGVS	Automated Guided Vehicle System
AHSS	Advanced High-Strength Steel
AI	Artificial Intelligence
APT	Automatic Programming of Tools
AQL	Acceptable Quality Limit (or Level)
ASCII	American Standard Code
AS/RS	Automatic Storage/Retrieval System
ATE	Automatic Test Equipment
AWJM	Abrasive Water Jet Machining
BASIC	Beginner's All-Purpose Symbolic Instruction Code
BTA	boring trepanning association
BTRI	Behind the Tape Reader Interface
BUE	built-up edge
CAD	Computer-Aided Design
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAD/D	Computer-Aided Drafting and Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAPP	Computer-Aided Process Planning
CATI	Computer-Aided Testing and Inspection
CDC	Cutter Diameter Compensation
CHM	Chemical Machining
CIM	Computer-Integrated Manufacturing
CL	Center Line
CMM	Coordinate Measuring Machine
CMS	Cellular Manufacturing System
CNC	Computer Numerical Control
COBOL	Common Business Oriented Language
CPR	Capacity Resources Planning
CPU	Central Processing Unit *(Computer)*
CRT	Cathode Ray Tube
CVD	Chemical Vapor Deposition
DBM	Data-base Management
CBN	cubic boron nitride
DBTT	Ductile-to-Brittle Transition Temperature
DCEN	Direct Current Electrode Negative
DCEP	Direct Current Electrode Positive
DDAS	Direct Data Acquisition System
DDC	Direct Digital Control
DDM	Direct Digital Manufacturing
DMD	Direct Metal Deposition
DNC	Digital (or Direct or Distributed) Numerical Control
DOC	depth of cut
DOI	depth of immersion
DOS	Disk Operating System
DP	Diametrical Pitch
DPRO	Digital Position Readout
DRO	Digital Readout
EAROM	Electrically-Alterable Read-Only Memory
EBCDIC	Extended Binary Coded Decimal Interchange Code
EBM	Electron Beam Machining *(EBW = Welding) (EBC = Cutting)*
ECM	Electrochemical Machining
ECO	engineering change order
EDM	Electrodischarge Machining *(EDG = Grinding)*
EMI	Electromagnetic Interface
EOB	End of Block
EOP	End of Program (workpiece)
EOT	End of Tape
EROM	Eraseable Read-Only Memory
ESW	Electroslag Welding
FATT	Fracture Appearance Transition Temperature
FCAW	Flux Cored Arc Welding
FDM	Fused Deposition Modeling
FEM	Finite-Element Method
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System
FORTRAN	Formula Translation
FRN	Feed Rate Number
FSW	Friction Stir Welding
GMAW	Gas Metal Arc Welding
GT	Group Technology
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
HERF	High Energy Rate Forming
HGVS	Human-Guided Vehicle System *(fork-lift with driver)*
HIP	Hot Isostatic Pressing
HP	horse power
HSLA	High-strength Low-alloy
HSS	high speed steel
IC	integrated circuit
ID	Inkjet Deposition
IGES	Initial Graphics Exchange System
IMPSs	Integrated Manufacturing Production Systems
I/O	Input/Output
IOCS	Input/Output Control System
JIT	Just-In-Time
LAN	Local Area Network

LASER	Light Amplification by Stimulated Emission of Radiation
LBM	Laser Beam Machining *(LBW = Welding) (LBC = Cutting)*
L-CMS	Linked-Cell Manufacturing System
LED	Light Emitting Diode
LE	lean engineering
LENS	Laser Engineered Net Shaping
LFG	low force grove
LOM	Laminated Object Manufacturing
LP	Lean Production
LSI	Large Scale Integration
MAP	Manufacturing Automation Protocol
MCU	Machine Control Unit
MDI	Manual Data Input
MIG	Metal-Inert Gas
MIM	Metal Injection Molding
MMFA	mixed model final assembly
MPS	Manufacturing Production System
mrp	Material Requirements Planning
MRPII	Manufacturing Resources Planning
MRR	metal removal rate
MSD	Manufacturing System Design
NC	Numerically Control
NDT	NonDestructive Testing *(NDE = Evaluation) (NDI = Inspection)*
OAW	Oxyacetylene Welding
OCR	Optical Character Recognition
OM	Orthogonal Machining
OPM	Orthogonal Plate Machining
OS	Operating System
OTT	Orthogonal Tube Turning
PAW	Plasma Arc Welding *(PAC = Cutting) (PAM = Machining)*
PC	process capability
PCB	Printed Circuit Board
PCN	polycrystalline cubic boron nitride
PD	Pitch Diameter
PDES	Product Design Exchange Specification
PIM	Powder Injection Molding
PLC	Programmable Logic Controller
POK	Production Ordering Kanban
POUS	point of use storage
PROM	Programmable Read-Only Memory
PS	Production System
P/M	Powder Metallurgy
PVD	Physical Vapor Deposition
QC	Quality Control
QMS	Quality Management System
RAM	Random Access Memory
RIM	Reaction Injection Molding
ROM	Read-Only Memory
RSW	Resistance Spot Welding
SAW	Submerged Arc Welding
SCA	Single Cycle Automatic
SEM	scanning electron microscope
SGC	Solid Ground Curing
SLA	Stereolithography Apparatus
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
SMAW	Shielded Metal Arc Welding
SMED	single minute exchange of dies
SPC	Statistical Process Control
SPF	Single Piece Flow
SQC	Statistical Quality Control
TCM	Thermochemical Machining
TIG	Tungsten Inert-Gas
TIR	Total Indicator Readout
TPS	Toyota Production System
TQC	Total Quality Control
UHSMC	Ultra-high-speed machining center
USM	Ultrasonic Machining *(USW = Welding)*
VA	Value Analysis
WAN	Wide Area Network
WIP	Work-In-Progress (or Process)
WJM	Water Jet Machining
WLK	Withdrawl Kanban
YAG	Yttrium-Aluminum Garnet

Chapter 1 Review Questions

SS Student Solution available in interactive e-text.

1. What role does manufacturing play relative to the standard of living of a country?

2. Aren't all goods really consumer goods, depending on how you define the customer? Discuss.

3. The Subway sandwich shop is an example of a job shop, a flow shop, or a project shop, which?

4. How does a system differ from a process? From a machine tool? From a job? From an operation?

5. SS Is a cutting tool the same thing as a machine tool? Discuss.

6. SS What are the major classifications of basic manufacturing processes?

7. Casting is often used to produce a complex-shaped part to be made from a hard-to-machine metal. How else could the part be made?

8. In the lost-wax casting process, what happens to the foam?

9. In making a gold medal, what do we mean by a "relief image" cut into the die?

10. How is a railroad station like a station on an assembly line?

11. SS Because no work is being done on a part when it is in storage, it does not cost you anything. True or false? Explain.

12. What forming processes are used to make a paper clip?

13. What is tooling in a manufacturing system?

14. It is acknowledged that chip-type machining is basically an inefficient process. Yet it is probably used more than any other to produce desired shapes. Why?

15. Compare Figures 1.1 and 1.16. What are the stages of the product life cycle for a computer?

16. In a modern safety razor with three or four blades that sells for $1, what do you think the cost of the blades might be?

17. SS List three purposes of packaging operations.

18. *Assembly* is defined as "the putting together of all the different parts to make a complete machine." Think of (and describe) an assembly process. Is making a club sandwich an assembly process? What about carving a turkey? Is this an assembly process?

19. What are the physical elements in a manufacturing system?

20. In the production system, who usually figures out how to make the product?

21. SS In Figure 1.8, what do the lines connecting the processes represent?

22. Characterize the process of squeezing toothpaste from a tube (extrusion of toothpaste) using Table 1.4 as a guideline. See the index for help on extrusion.

23. It has been said that low-cost products are more likely to be more carefully designed than high-priced items. Do you think this is true? Why or why not?

24. Proprietary processes are closely held or guarded company secrets. The chemical makeup of a lubricant for an extrusion process is a good example. Give another example of a proprietary process.

25. If the rolls for the cold-rolling mill that produces the sheet metal used in your car cost $300,000 to $400,000, how is it that your car can still cost less than $20,000?

26. SS Make a list of service systems, giving an example of each.

27. What is the fundamental difference between a service system and a manufacturing system?

28. In the process of buying a calf, raising it to a cow, and disassembling it into "cuts" of meat for sale, where is the "value added"?

29. What kind of process is powder metallurgy: casting or forming?

30. In view of Figure 1.2, who really determines the selling price per unit?

31. What costs make up manufacturing cost (sometimes called factory cost)?

32. SS What are major phases of a product life cycle?

33. How many different manufacturing systems might be used to make a component with annual projected sales of 16,000 parts per year with 10 to 12 different models (varieties)?

34. In general, as the annual volume for a product increases, the unit cost decreases. Explain.

Chapter 1 Problems

1. The Toyota truck plant in Indiana produces 150,000 trucks per year. The plant runs one eight-hour shift and makes 400 trucks per day. About 1300 people work on the final assembly line. Each truck has about 20 direct labor hours per car in it.

a. Assuming the truck sells for $26,000 and workers earn $50 per hour in wages and benefits, what percentage of the cost of the truck is in direct labor?

b. What is the production rate of the final assembly line?

2. A company is considering making automobile bumpers from aluminum instead of from steel. List some of the factors it would have to consider in arriving at its decision.

3. Many companies are critically examining the relationship of product design to manufacturing and assembly. Why do they call this concurrent engineering?

4. We can analogize your university to a manufacturing system that produces graduates. Assuming that it takes 4 years to get a college degree and that each course really adds value to the student's knowledge base, what percentage of the 4 years is "value adding" (percentage of time in class plus two hours of preparation for each hour in class)?

5. What kind of manufacturing system (design) is your university?

6. What are the major process steps in the assembly of a subway sandwich?

7. What is the relationship between Figures 1.2 and 1.4?

8. Recently, National Geographic magazine asked the US librarian of Congress to compile a listing of the 10 most meaningful advances in history—inventions and innovations of significance to modern life. The "Top Ten Innovations" list that was compiled included: (1) Printing press, (2) Light bulb, (3) Airplane, (4) Personal computer, (5) Vaccines, (6) Automobile, (7) Clock, (8) Telephone, (9) Refrigeration, and (10) Camera.

1. Select one of the items from the list and discuss the materials or materials advances that enabled its creation.

2. For the same item selected in Part 1, discuss the manufacturing processes, or process advances, that enabled its creation.

3. If new items were to be added to the list over the next 10 to 20 years, what do you think they would be?

4. For items suggested in Part 3, what materials or process advances would have been instrumental in their development and use?

Chapter 1 Key Words

assembly
casting
construction
consumer goods
continuous process
design engineer
fabricating
finishing process
flow shop
forming
goods
group technology (GT)
heat treatment
industrial engineer
inspection
job
job shop
joining process
lean engineer
lean production
linked-cell manufacturing system (L-CMS)
machine tool
machining
manufacturing
manufacturing cost
manufacturing engineer
manufacturing process
manufacturing system
materials engineer
metal cutting
metal removal
molding
numerical control
operation
packaging
processing
producer goods
product
product life cycle
production system
project shop
services
shearing
shelf life
station
storage
sustaining technology
tooling
tool
Toyota Production System

Chapter 1 CASE STUDY Famous Manufacturing Engineers

Manufacturing engineering is that engineering function charged with the responsibility of interpreting product design in terms of manufacturing requirements and process capability. Specifically, the manufacturing engineer (MfE) may:

- Determine how the product is to be made in terms of specific manufacturing processes.
- Design workholding and work transporting tooling or containers.
- Select the tools (including the tool materials) that will machine or form the work materials.
- Select, design, and specify devices and instruments that inspect products that have been manufactured to determine their quality.
- Design and evaluate the performance of the manufacturing system.
- Perform all these functions (and many more) related to the actual making of the product at the most reasonable cost per unit without sacrifice of the functional requirements or the users' service life.

There's no great glory in being a great MfE. If you want to be an MfE, you had better be ready to get your hands dirty. Of course, there are exceptions. There have been some very famous MfEs. For example:

- John Wilkinson of Bersham, England, built a boring mill in 1775 to bore the cast iron cylinders for James Watt's steam engine. How good was this machine?
- Eli Whitney was said to have invented the cotton gin, a machine to separate seeds from cotton. His machine was patented but was so simple, anyone could make one. He was credited with "interchangeability"—but we know Thomas Jefferson observed interchangeability in France in 1785 and probably the French gunsmith LeBlanc is the real inventor here. Jefferson tried to bring the idea to America, and Whitney certainly did. He took 10 muskets to Congress, disassembled them, and scattered the pieces. Interchangeable parts permitted them to be reassembled. He was given a contract for 2000 guns to be made in 2 years. But what is the rest of his story?
- Joe Brown started a business in Rhode Island in 1833 making lathes and small tools as well as timepieces (watchmaker). Lucian Sharp joined the company in 1848 and developed a pocket sheet metal gage in 1877 and a 1-in. micrometer, and in 1862 developed the universal milling machine.
- At age 16, Sam Colt sailed to Calcutta on the Brig "Curve." He whittled a wood model of a revolver on this voyage. He saved his money and had models of a gun built in Hartford by Anson Chase, for which he got a patent. He set up a factory in New Jersey—but he could not sell his guns to the Army because they were too complicated. He sold to the Texas Rangers and the Florida Frontiersmen, but he had to close the plant. In 1846, the Mexican war broke out. General Zachary Taylor and Captain Sam Walters wanted to buy guns. Colt had none but accepted orders for 1000 guns and constructed a model (Walker Colt); he arranged to have them made at Whitney's (now 40-year-old) plant in Whitneyville. Here he learned about mass production methods. In 1848, he rented a plant in Hartford, Connecticut, and the Colt legend spread. In 1853, he had built one of the world's largest arms plant in Connecticut, which had 1400 machine tools. Colt helped start the careers of
  - E. K. Root, mechanic and superintendent, paying him a salary of $25,000 in the 1800s. Abolished hand work—jigs and fixtures.
  - Francis Pratt and Amos Whitney—famous machine tool builders.
  - William Gleason—gear manufacturer.
  - E. P. Bullard—invented the Mult–An–Matic Multiple spindle machine, which cut the time to make a flywheel from 18 minutes to slightly over 1 minute. Sold this to Ford.
  - Christopher Sponer.
  - E. J. Kingsbury—invented a drilling machine to drill holes through toy wheel hubs that had a spring-loaded cam that enabled the head to sense the condition of the casting and modify feed rate automatically.

Now here are some more names from the past of famous and not-so-famous manufacturing, mechanical, and industrial engineers. Relate them to the development of manufacturing processes or manufacturing system designs.

- Eli Whitney
- Henry Ford
- Charles Sorenson
- Sam Colt
- John Parsons
- Eiji Toyoda
- Elisha Root
- John Hall
- Thomas Blanchard
- Fred Taylor
- Taiichi Ohno
- Ambrose Swasey

CHAPTER 1

Introduction to DeGarmo's Materials and Processes in Manufacturing

1.1 Materials, Manufacturing, and the Standard of Living

Manufacturing is critical to a country's economic welfare and standard of living because the standard of living in any society is determined, primarily, by the *goods* and *services* that are available to its people. Manufacturing companies contribute about 20% of the GNP, employ about 18% of the workforce, and account for 40% of the exports of the United States. In most cases, materials are utilized in the form of manufactured goods. **Manufacturing** and **assembly** represent the organized activities that convert raw materials into salable goods. The manufactured goods are typically divided into two classes: producer goods and consumer goods. **Producer goods** are those goods manufactured for other companies to use to manufacture either producer or consumer goods. **Consumer goods** are those purchased directly by the consumer or the general public. For example, someone has to build the machine tool (a lathe) that produces (using machining processes) the large rolls that are sold to the rolling mill factory to be used to roll the sheets of steel that are then formed (using dies) into body panels of your car. Similarly, many service industries depend heavily on the use of manufactured products, just as the agricultural industry is heavily dependent on the use of large farming machines for efficient production.

Processes convert materials from one form to another adding value to them. The more efficiently materials can be produced and converted into the desired products that function with the prescribed quality, the greater will be the companies' productivity and the better will be the standard of living of the employees.

The history of mankind has been linked to our ability to work with tools and materials, beginning with the Stone Age and ranging through the eras of copper and bronze, the Iron Age, and recently the age of steel. Although ferrous materials still dominate the manufacturing world, we have entered the age of tailor-made plastics, composite materials, and exotic alloys.

A good example of this progression is shown in **Figure 1.1**. The goal of the manufacturer of any product or service is to continually improve. For a given product or service, this improvement process usually follows an S-shaped curve, as shown in Figure 1.1a, often called a product life-cycle curve. After the initial invention/creation and development, a period of rapid growth in performance occurs, with relatively few resources required. However, each improvement becomes progressively more difficult. For a significant gain, more money and time and innovation are required. Finally, the product or service enters the maturity phase, during which additional performance gains become very costly.

For example, in the automobile tire industry, Figure 1.1b shows the evolution of radial tire performance from its birth in 1946 to the present. Growth in performance is actually the superposition of many different improvements in material, processes, and design.

These innovations, known as **sustaining technology**, serve to continually bring more value to the consumer of existing products and services. In general, sustaining manufacturing technology is the backbone of American industry and the ever-increasing productivity metric.

Although materials are no longer used only in their natural state, there is obviously an absolute limit to the amounts of many materials available here on earth. Therefore, as the variety of man-made materials continues to increase, resources must be used efficiently and recycled whenever possible. Of course, recycling only postpones the exhaustion date.

Like materials, processes have also proliferated greatly in the past 50 years, with new processes being developed to handle the new materials more efficiently and with less waste. A good example is the laser, invented around 1960, which now finds many uses

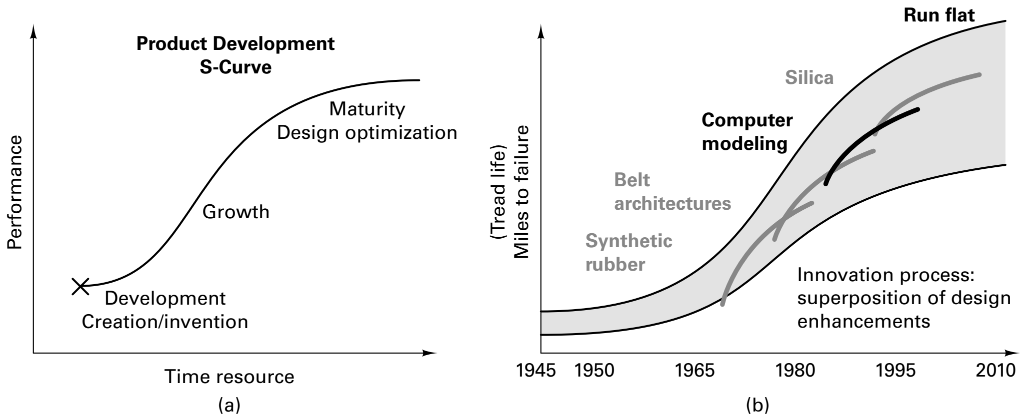

FIGURE 1.1 (a) A product development curve usually has an "S"-shape. (b) Example of the S-curve for the radial tire. (Courtesy of Bart Thomas, Michelin.)

in machining, measurement, inspection, heat treating, welding, additive manufacturing, surgery, and many more. New developments in manufacturing technology often account for improvements in productivity. Even when the technology is proprietary, the competition often gains access to it, usually quite quickly.

Starting with the product design, materials, labor, and equipment are interactive factors in manufacturing that must be combined properly (integrated) to achieve low cost, superior quality, and on-time delivery. **Figure 1.2** shows a breakdown of costs for a product (like a car). Typically about 40% of the selling price of a product is the **manufacturing cost**. Because the selling price determines how much the customer is willing to pay, maintaining the profit often depends on reducing manufacturing cost. The internal customers who really make the product are called direct labor. They are usually the targets of automation, but typically they account for only about 10% of the manufacturing cost, even though they are the main element in increasing productivity. In Chapters 42 and 43, a new manufacturing strategy is presented that attacks the materials cost, indirect costs, and general administration costs, in addition to labor costs. The materials costs include the cost of storing and handling the materials within the plant. The strategy depends on a new factory design and is called **lean production**.

Referring again to the total expenses shown in Figure 1.2 (selling price less profit), about 68% of dollars are spent on people, but only 5% to 10% on director labor, the breakdown for the rest being about 15% for engineers and 25% for marketing, sales, and general management people. The average labor cost in manufacturing in the United States is $10 to $25 per hour for hourly workers. Reductions in direct labor will have only marginal effects on the total people costs. The optimal combination of factors for producing a small quantity of a given product may be very inefficient for a larger quantity of the same product. Consequently, a systems approach, taking all the factors into account, must be used. This requires a sound and broad understanding on the part of the decision makers on the value of materials, processes, and equipment to the company, and their customers, accompanied by an understanding of the manufacturing systems. Materials, processes, and manufacturing systems are what this book is all about.

1.2 Manufacturing and Production Systems

Manufacturing is the economic term for making goods and services available to satisfy human wants. Manufacturing implies creating value by applying useful mental or physical labor.

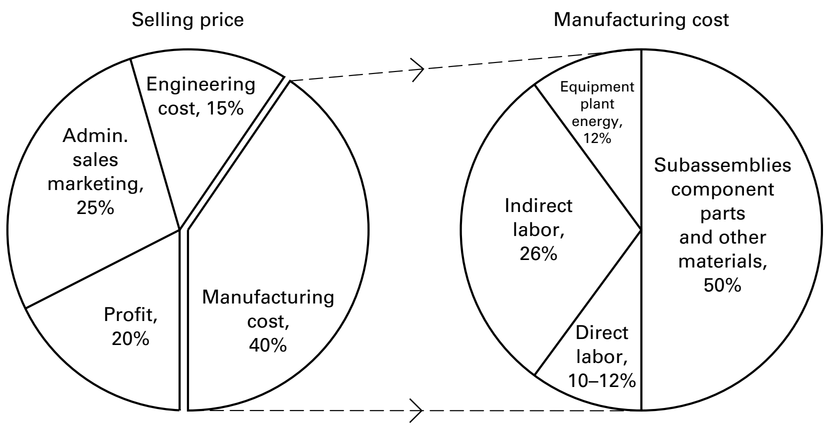

FIGURE 1.2 Manufacturing cost is the largest part of the selling price, usually around 40%. The largest part of the manufacturing cost is materials, usually 50%.

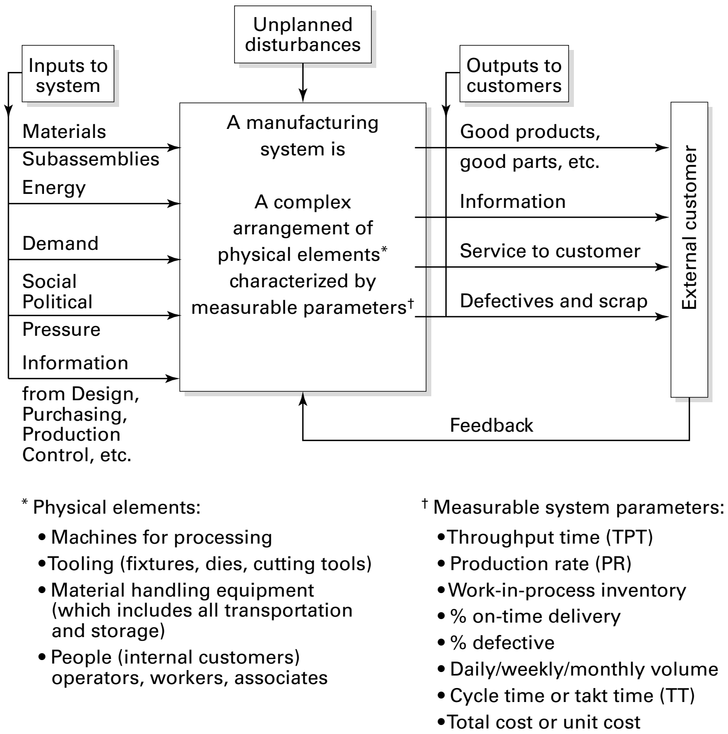

FIGURE 1.3 Here is our definition of a manufacturing system with its inputs and outputs. (From Design of the Factory with a Future, 1991, McGraw-Hill, by J. T. Black.)

The *manufacturing processes* are arranged in the factory to form a *manufacturing system* (MS). The manufacturing system is a complex arrangement of physical elements characterized by measurable parameters. The manufacturing system takes inputs and produces products for the external customer, as shown in **Figure 1.3**.

The inputs to the manufacturing system includes materials, information, and energy. The system is a complex set of elements that includes machines (or machine tools), people, materials-handling equipment, and tooling. Workers are the internal customers. They process materials within the system, which gain value as the material progresses from process to machine. Manufacturing system outputs may be finished or semifinished goods. Semifinished goods serve as inputs to some other process at other locations. Manufacturing systems are dynamic, meaning that they must be designed to adapt constantly to change. Many of the inputs cannot be fully controlled by management, and the effect of disturbances must be counteracted by manipulating the controllable inputs or the system itself. Controlling the input material availability and/or predicting demand fluctuations may be difficult. A national economic decline or recession can cause shifts in the business environment that can seriously change any of these inputs. In manufacturing systems, not all inputs are fully controllable. To understand how manufacturing systems work and be able to design manufacturing systems, computer modeling (simulation) and analysis are used. However, modeling and analysis are difficult because

1. In the absence of a system design, the manufacturing systems can be very complex, be difficult to define, and have conflicting goals.
2. The data or information may be difficult to secure, inaccurate, conflicting, missing, or even too abundant to digest and analyze.
3. Relationships may be awkward to express in analytical terms, and interactions may be nonlinear; thus, many analytical tools cannot be applied with accuracy. System size may inhibit analysis.
4. Systems are always dynamic and change during analysis. The environment can change the system, and vice versa.
5. All systems analyses are subject to errors of omission (missing information) and commission (extra information). Some of these are related to breakdowns or delays in feedback elements.

Because of these difficulties, digital simulation has become an important technique for manufacturing systems modeling and analysis as well as for manufacturing system design.

The entire company is often referred to as the enterprise or the production system. The production system services the manufacturing system, as shown in **Figure 1.4**. In this book, a production system will refer to the total company and will include within it the manufacturing system. The production system includes the manufacturing system plus all the other functional areas of the plant for information, design, analysis, and control. These subsystems are connected by various means to each other to produce either goods or services or both.

Goods refers to material things. **Services** are nonmaterial things that we buy to satisfy our wants, needs, or desires. Service production systems include transportation, banking, finance, savings and loan, insurance, utilities, health care, education, communication, entertainment, sporting events, and

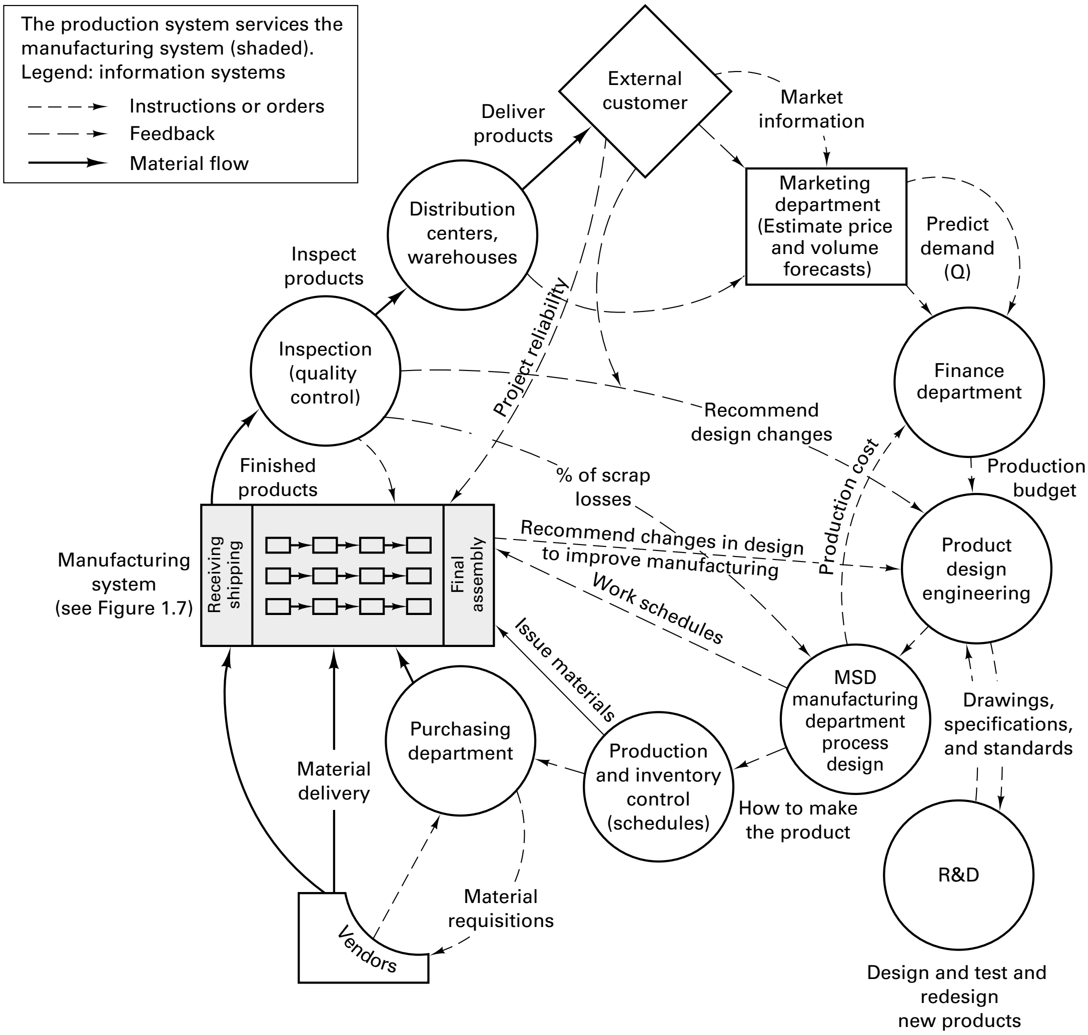

FIGURE 1.4 The production system includes and services the manufacturing system. The functional departments are connected by formal and informal information systems, designed to service the manufacturing that produces the goods.

so forth. They are useful labors that do not directly produce a product. Manufacturing has the responsibility for designing processes (sequences of operations and processes) and systems to create (make or manufacture) the product as designed. The system must exhibit flexibility to meet customer demand (volumes and mixes of products) as well as changes in product design.

As shown in **Table 1.1**, production terms have a definite rank of importance, somewhat like rank in the army. Confusing *system* with *section* is similar to mistaking a colonel for a corporal. In either case, knowledge of rank is necessary. The terms tend to overlap because of the inconsistencies of popular usage.

An obvious problem exists here in the terminology of manufacturing and production. The same term can refer to different things. For example, *drill* can refer to the machine tool that does these kinds of operations; the operation itself, which can be done on many different kinds of machines; or the cutting tool, which exists in many different forms. It is therefore important to use modifiers whenever possible: "Use the *radial* drill *press* to drill a hole using a 1-in.-diameter spade drill." The emphasis of this book will be directed toward the understanding of the processes, machines, and tools required for manufacturing and how they interact with the materials being processed. In the last chapters of the book, an introduction to systems aspects is presented.

Production System—The Enterprise

The highest-ranking term in the hierarchy is **production system**. A production system includes people, money, equipment, materials and supplies, markets, management, and the manufacturing system. In fact, all aspects of commerce (manufacturing, sales, advertising, profit, and distribution) are involved. **Table 1.2** provides a partial list of production systems. Another term for them is "industries" as in the "aerospace industry." Further discussion on the enterprise is found in Chapter 42.

Much of the information given for manufacturing systems is relevant to the service system. Most require a service

TABLE 1.1 Production Terms for Manufacturing Production Systems

Term	Meaning	Examples
Production system; the enterprise	All aspects of workers, machines, and information, considered collectively, needed to manufacture parts or products; integration of all units of the system is critical.	Company that makes engines, assembly plant, glassmaking factory, foundry; sometimes called the enterprise or the business.
Manufacturing system (sequence of operations, collection of processes) or factory	The collection of manufacturing processes and operations resulting in specific end products; an arrangement or layout of many processes, materials-handling equipment, and operators.	Rolling steel plates, manufacturing of automobiles, series of connected operations or processes, a job shop, a flow shop, a continuous process.
Machine or machine tool or manufacturing process	A specific piece of equipment designed to accomplish specific processes, often called a *machine tool*; machine tools linked together to make a manufacturing system.	Spot welding, milling machine, lathe, drill press, forge, drop hammer, die caster, punch press, grinder, etc.
Job (sometimes called a *station*; a collection of tasks)	A collection of operations done on machines or a collection of tasks performed by one worker at one location on the assembly line.	Operation of machines, inspection, final assembly; e.g., forklift driver has the job of moving materials.
Operation (sometimes called a *process*)	A specific action or treatment, often done on a machine, the collection of which makes up the job of a worker.	Drill, ream, bend, solder, turn, face, mill extrude, inspect, load.
Tools or tooling	Refers to the implements used to hold, cut, shape, or deform the work materials; called *cutting tools* if referring to machining; can refer to *jigs* and *fixtures* in workholding and *punches* and *dies* in metal forming.	Grinding wheel, drill bit, end milling cutter, die, mold, clamp, three-jaw chuck, fixture.

TABLE 1.2 Partial List of Production Systems for Producer and Consumer Goods

Aerospace and airplanes	Foods (canned, dairy, meats, etc.)
Appliances	Footwear
Automotive (cars, trucks, vans, wagons, etc.)	Furniture
Beverages	Glass
Building supplies (hardware)	Hospital suppliers
Cement and asphalt	Leather and fur goods
Ceramics	Machines
Chemicals and allied industries	Marine engineering
Clothing (garments)	Metals (steel, aluminum, etc.)
Construction	Natural resources (oil, coal, forest, pulp and paper)
Construction materials (brick, block, panels)	Publishing and printing (books, CDs, newspapers)
Drugs, soaps, cosmetics	Restaurants
Electrical and microelectronics	Retail (food, department stores, etc.)
Energy (power, gas, electric)	Ship building
Engineering	Textiles
Equipment and machinery (agricultural, construction and electrical products, electronics, household products, industrial machine tools, office equipment, computers, power generators)	Tire and rubber Tobacco Transportation vehicles (railroad, airline, truck, bus) Vehicles (bikes, cycles, ATVs, snowmobiles)

production system (SPS) for proper product sales. This is particularly true in industries, such as the food (restaurant) industry, in which customer service is as important as quality and on-time delivery. **Table 1.3** provides a short list of service industries.

TABLE 1.3 Types of Service Industries

Advertising and marketing
Communication (telephone, computer networks)
Education
Entertainment (radio, TV, movies, plays)
Equipment and furniture rental
Financial (banks, investment companies, loan companies)
Health care
Insurance
Transportation and car rental
Travel (hotel, motel, cruise lines)

Manufacturing Systems

A collection of operations and processes used to obtain a desired product(s) or component(s) is called a **manufacturing system**. The manufacturing system design is therefore the arrangement of the manufacturing processes in the factory. Control of a system applies to overall control of the whole, not merely of the individual processes or equipment. The entire manufacturing system must be controlled to schedule and control the factory—all its inputs, inventory levels, product quality, output rates, and so forth.

Manufacturing Processes

A **manufacturing process** converts unfinished materials to finished products, often using machines or machine tools. For example, injection molding, die casting, progressive stamping, milling, arc welding, painting, assembling, testing, pasteurizing, homogenizing, and annealing are commonly called processes or manufacturing processes. The term *process* can also refer to a sequence of steps, processes, or operations for production of goods and services, as shown in **Figure 1.5**, which shows the processes to manufacture an Olympic-type medal.

A **machine tool** is an assembly of related mechanisms on a frame or bed that together produce a desired result. Generally, motors, controls, and auxiliary devices are included. Cutting tools and workholding devices are considered separately.

A machine tool may do a single process (e.g., cutoff saw) or multiple processes, or it may manufacture an entire component. Machine sizes vary from a tabletop drill press to a 1000-ton forging press.

Job and Station

In the classical manufacturing system, a **job** is the total of the work or duties a worker performs. A **station** is a location or area where a production worker performs tasks or a job.

A job is a group of related operations and tasks performed at one station or series of stations in cells. For example, the job at a final assembly station may consist of four tasks:

1. Attach carburetor
2. Connect gas line
3. Connect vacuum line
4. Connect accelerator rod

The job of an operator of a turret lathe (a semiautomatic machine tool) may include the following operations and tasks: load, start, index and stop, unload, inspect. The operator's job may also include setting up the machine (i.e., getting ready for manufacturing). Other machine operations include drilling, reaming, facing, turning, chamfering, and knurling. The operator can run more than one machine or service at more than one station.

The terms *job* and *station* have been carried over to unmanned machines. A job is a group of related operations generally performed at one station, and a station is a position or location in a machine (or process) where specific operations are performed. A simple machine may have only one station. Complex machines can be composed of many stations. The job at a station often includes many simultaneous operations, such as "drill all five holes" by multiple spindle drills. In the planning of a job, a process plan is often developed (by the engineer) to describe how a component is made using a sequence of operations. The engineer begins with a part drawing and selects the raw material. Follow in **Figure 1.6** the sequence of machining operations that transforms the cylinder in a pinion shaft.

Operation

An **operation** is a distinct action performed to produce a desired result or effect. Typical manual machine operations are loading and unloading. Operations can be divided into suboperational elements. For example, loading is made up of picking up a part, placing part in jig, and closing jig. However, suboperational elements will not be discussed here.

Operations categorized by function are

1. *Materials handling and transporting:* change in the location or position of the product.
2. *Processing:* change in volume and quality, including assembly and disassembly; can include packaging.
3. *Packaging:* special processing; may be temporary or permanent for shipping.
4. *Inspecting and testing:* comparison to the standard or check of process behavior.
5. *Storing:* time lapses without further operations.

These basic operations may occur more than once in some processes, or they may sometimes be omitted. *Remember, it is the manufacturing processes that add value and quality to the materials*. Defective processes produce poor quality or scrap. Other operations may be necessary but do not, in general, add value, whereas operations performed by machine tools that do material processing usually do add value.

Treatments

Treatments operate continuously on the workpiece. They usually alter or modify the product-in-process without tool contact. Heat treating, curing, galvanizing, plating, finishing, (chemical) cleaning, and painting are examples of treatments. Treatments usually add value to the part.

These processes are difficult to include in manufacturing cells because they often have long cycle times, are hazardous to the workers' health, or are unpleasant to be around because of high heat or chemicals. They are often done in large tanks or furnaces or rooms. The cycle time for these processes may dictate the cycle times for the entire system. These operations also tend to be material specific. Many manufactured products are given decorative and protective surface treatments that control the finished appearance. A customer may not buy a new vehicle because it has a visible defect in the chrome bumper, although this defect will not alter the operation of the car.

Tools, Tooling, and Workholders

The lowest mechanism in the production term rank is the **tool**. Tools are used to hold, cut, shape, or form the unfinished product. Common hand tools include the saw, hammer, screwdriver, chisel, punch, sandpaper, drill, clamp, file, torch, and grindstone.

Basically, mechanized versions of such hand tools are called cutting tools. Some examples of tools for cutting are drill bits, reamers, single-point turning tools, milling cutters, saw blades, broaches, and grinding wheels. Noncutting tools for forming include extrusion dies, punches, and molds.

Tools also include workholders, jigs, and fixtures. These tools and cutting tools are generally referred to as the **tooling**, which usually must be considered (purchased) separate from machine tools. Cutting tools wear and fail and must be periodically replaced before parts are ruined. The workholding devices

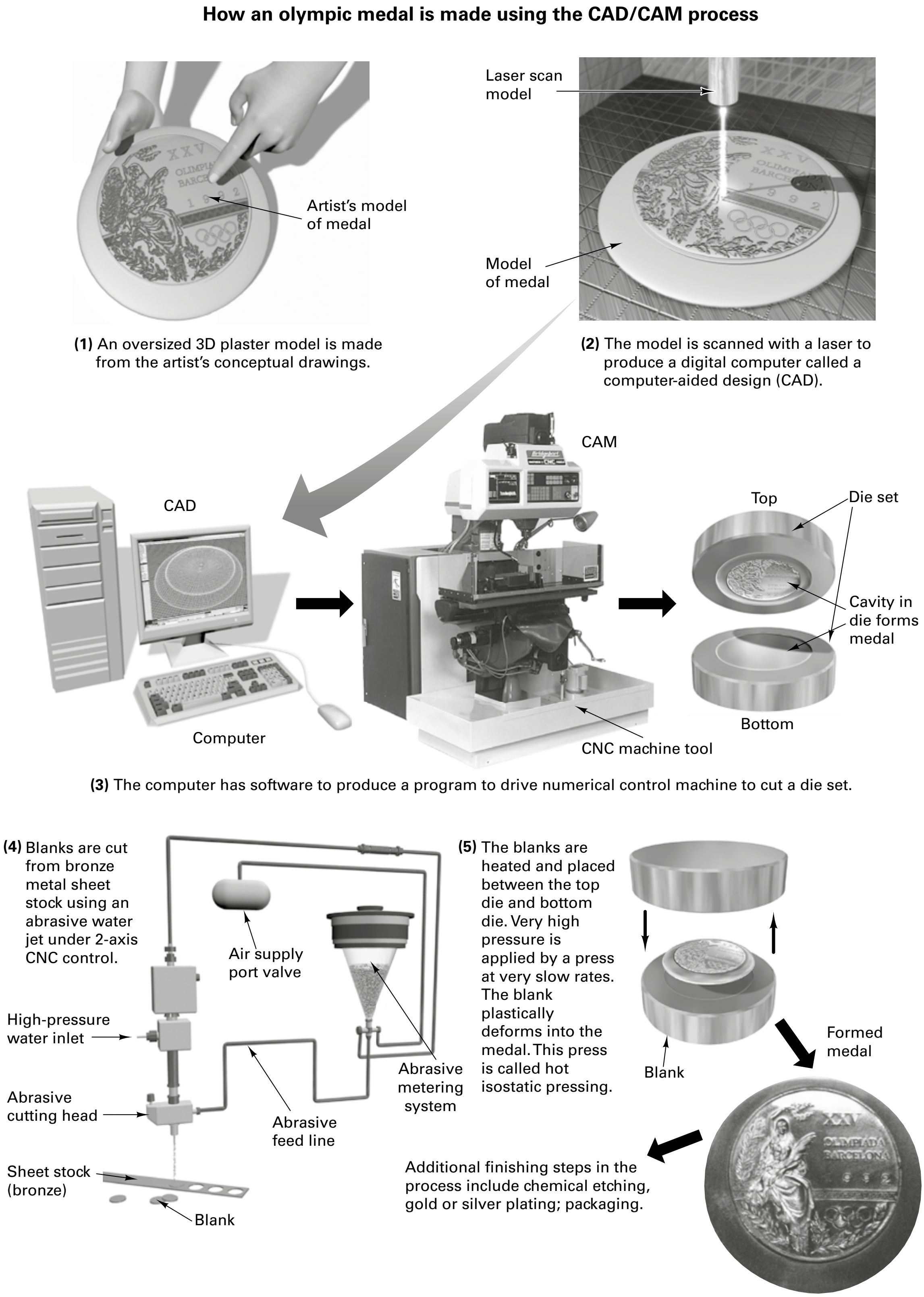

FIGURE 1.5 The manufacturing process for making Olympic medals has many steps or operations, beginning with design and including die making. (Courtesy J. T. Black.)

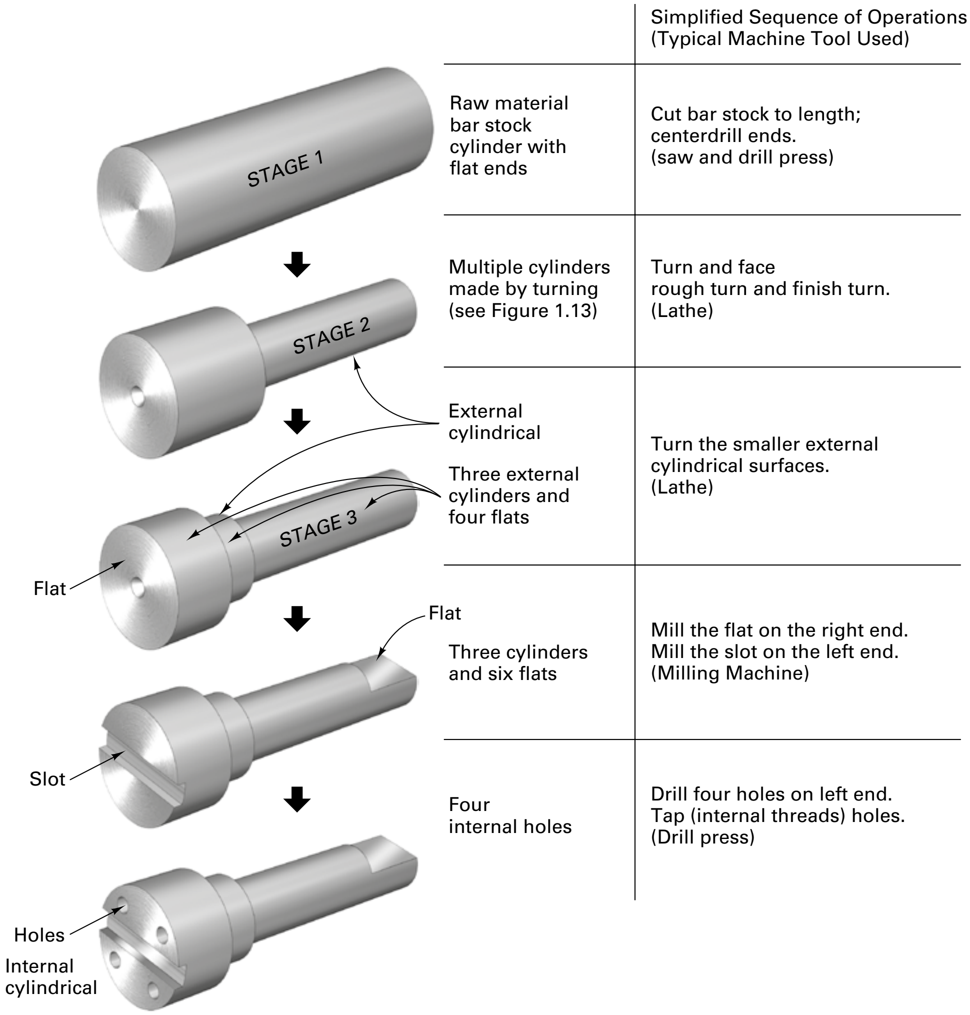

FIGURE 1.6 The component called a pinion shaft is manufactured by a "sequence of operations" to produce various geometric surfaces. The engineer determines the sequence and selects the processes and tooling needed to make the component.

must be able to locate and secure the workpieces during processing in a repeatable, mistake-proof way.

Tooling for Measurement and Inspection

Measuring tools and instruments are also important for manufacturing. Common examples of measuring tools are rulers, calipers, micrometers, and gages. Precision devices that use laser optics or vision systems coupled with sophisticated electronics are becoming commonplace. Vision systems and coordinate measuring machines are becoming critical elements for achieving superior quality.

Integrating Inspection into the Process

The integration of the **inspection** process into the manufacturing process or the manufacturing system is a critical step toward building products of superior quality. An example will help. Compare an electric typewriter with a computer that does word processing. The electric typewriter is flexible. It types whatever words are wanted in whatever order. It types a specific font and type size. The computer can do all of this but can also, through its software, change font or type size, set italics; set bold, dark type; vary the spacing to justify the right margin; plus many other functions. It checks immediately for incorrect spelling and other defects like repeated words. The software system provides a signal to the hardware to flash the word so that the operator will know something is wrong and can make an immediate correction. If the system were designed to prevent the typist from typing repeated words, then this would be a *poka-yoke*, a term meaning defect prevention. Defect prevention is better than immediate defect detection and correction. Ultimately, the system should be able to forecast the probability of a defect, correcting the problem at the source. This means that the typist would have to be removed from the process loop, perhaps by having the system type out what it is told (convert oral to written directly). Poka-yoke devices and source inspection techniques are keys to designing manufacturing systems that produce superior-quality products at low cost.

Products and Fabrications

In manufacturing, material things (goods) are made to satisfy human wants. **Products** result from manufacturing, which also includes conversion processes such as refining, smelting, and mining.

Products can be manufactured by fabricating or by processing. **Fabricating** is the manufacture of a product from pieces such as parts, components, or assemblies. Individual products or parts can also be fabricated. Separable discrete items such as tires, nails, spoons, screws, refrigerators, or hinges are fabricated.

Processing is also used to refer to the manufacture of a product by continuous means, or by a continuous series of operations, for a specific purpose. Continuous items such as steel strip, beverages, breakfast foods, tubing, chemicals, and petroleum are "processed." Many processed products are marketed as discrete items, such as bottles of beer, bolts of cloth, spools of wire, and sacks of flour.

Separable discrete products, both piece parts and assemblies, are fabricated in a plant, factory, or mill, for instance, a textile or rolling mill. Products that flow (liquids, gases, grains, or powders) are processed in a *plant* or *refinery*. The *continuous-process industries* such as petroleum and chemical plants are sometimes called processing industries or flow industries.

To a lesser extent, the terms *fabricating industries* and *manufacturing industries* are used when referring to fabricators or manufacturers of large products composed of many parts, such as a car, a plane, or a tractor. Manufacturing often includes continuous-process treatments such as electroplating, heating, demagnetizing, and extrusion forming.

Construction or building is making goods by means other than manufacturing or processing in factories. Construction is a form of project manufacturing of useful goods like houses, highways, and buildings. The public may not consider construction as manufacturing because the work is not usually done in a plant or factory, but it can be. Companies can now build a custom house of any design in a factory, truck it to the building site, and assemble it on a foundation in two or three weeks.

Agriculture, fisheries, and commercial fishing produce real goods from useful labor. Lumbering is similar to both agriculture and mining in some respects, and mining should be considered processing. Processes that convert the raw materials from agriculture, fishing, lumbering, and mining into other usable and consumable products are also forms of manufacturing.

Workpiece and Its Configuration

In the manufacturing of goods, the primary objective is to produce a component having a desired geometry, size, and finish. Every component has a shape that is bounded by various types of surfaces of certain sizes that are spaced and arranged relative to each other. Consequently, a component is manufactured by producing the surfaces that bound the shape. Surfaces may be:

1. Plane or flat.
2. Cylindrical (external or internal).
3. Conical (external or internal).
4. Irregular (curved or warped).

Figure 1.6 illustrates how a shape can be analyzed and broken up into these basic bounding surfaces. Parts are manufactured by using a set or sequence of processes that will (1) remove portions of a rough block of material (bar stock, casting, forging) to produce and leave the desired bounding surface; (2) add portions of material (welding, additive manufacturing); or (3) cause material to form into a stable configuration that has the required bounding surfaces (casting, forging). Consequently, in designing an object, the designer specifies the shape, size, and arrangement of the bounding surface. The part design must be analyzed to determine what materials will provide the desired properties, including mating to other components, and what processes can best be employed to obtain the end product at the most reasonable cost. This is often the job of the engineer.

Roles of Engineers in Manufacturing

Many engineers have as their function the designing of products. The products are brought into reality through the processing or fabrication of materials. In this capacity designers are a key factor in the material selection and manufacturing procedure. A **design engineer**, better than any other person, should know what the design is to accomplish, what assumptions can be made about service loads and requirements, what service environment the product must withstand, and what appearance the final product is to have. To meet these requirements, the material(s) to be used must be selected and specified. In most cases, to utilize the material and to enable the product to have the desired form, the designer knows that certain manufacturing processes will have to be employed. In many instances, the selection of a specific material may dictate what processing must be used. On the other hand, when certain processes must be used, the design may have to be modified for the process to be utilized effectively and economically. Certain dimensional sizes can dictate the processing, and some processes require certain sizes for the parts going into them. In converting the design into reality, many decisions must be made. In most instances, they can be made most effectively at the design stage. It is thus apparent that design engineers are a vital factor in the manufacturing process, and it is indeed a blessing to the company if they can *design for manufacturing*, that is, design the product so that it can be manufactured and/or assembled economically (i.e., at low unit cost). Design for manufacturing uses the knowledge of manufacturing processes, and so the design and manufacturing engineers should work together to integrate design and manufacturing activities.

Manufacturing engineers select and coordinate specific processes and equipment to be used or supervise and manage their use. Some design special tooling so that standard machines can be utilized in producing specific products. These engineers must have a broad knowledge of manufacturing processes and material behavior so that desired operations can be