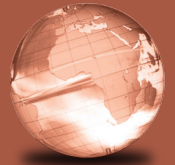


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Manufacturing Engineering and Technology

Eighth Edition in SI Units

Serope Kalpakjian | Steven R. Schmid



Manufacturing Engineering and Technology

EIGHTH EDITION IN SI UNITS

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Dedicated to our families, whose patience and support made this book possible.

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Preface

Since the mid-2000s, manufacturing has undergone a rebirth in its development and research activities. With the recognition that manufacturing adds value to products, and wealth to national economies, governments around the world have been investing in their infrastructure and are now partnering with industry to bring new manufacturing capabilities to the global marketplace.

Manufacturing continues to be a dynamic activity, providing all-encompassing opportunities for contributions from several traditional disciplines. The proliferation of powerful software and Internet communication tools, especially their wireless capabilities, has made new approaches possible. The engineering terminology now includes such terms as Big Data, mass customization, cobots, and cybersecurity. Traditional manufacturing approaches and the materials involved are constantly being adjusted for ever-increasing efficiency and continuous improvements in performance.

In view of the advances being made in all aspects of manufacturing, the authors have continued their efforts to present a comprehensive, balanced, and, most importantly, an up-to-date coverage of the science, engineering, and technology of manufacturing. As in its previous editions, this text maintains the same number of chapters, while continuing to emphasize the interdisciplinary nature of all manufacturing activities, including complex interactions among materials, design, and manufacturing processes and operations.

Every attempt has been made to motivate and challenge students to understand and develop an appreciation of the vital importance of manufacturing in the modern global economy. The extensive questions and problems, at the end of each chapter, are designed to encourage students to explore viable solutions to a wide variety of challenges, giving them an opportunity to describe and assess the capabilities as well as limitations of all manufacturing processes and operations. These challenges include economic considerations and the competitive aspects in a global marketplace. The numerous examples and case studies throughout the book also help give students a perspective on real-world applications of the topics described throughout the book.

What's New in This Edition

- The eighth edition has been thoroughly updated, with numerous new topics and illustrations relevant to all aspects of manufacturing. See the table on page 23 for specifics.
- Wherever appropriate, illustrations and examples have been replaced, indicating recent advances in manufacturing.
- The text contains more cross references to other relevant sections, tables, and illustrations in the book.
- The Questions, Qualitative Problems, Quantitative Problems, and Design/Projects at the end of each chapter have been expanded.
- The Bibliographies at the end of each chapter have been thoroughly updated.
- *Manufacturing Engineering and Technology* is also available as an eText. Pearson eText offers a simple-to-use, mobile-optimized, personalized reading experience. It lets students add bookmarks, highlight, and take notes all in one place, even when offline. Seamlessly integrated videos engage students and give them access to the help they need, when they need it. Educators can easily schedule readings and share their own notes with students so they see the connection between their eText and what they learn in class—motivating them to keep reading, and keep learning. And, reading analytics offer insight into how students use the eText, helping educators tailor their instruction.

- The Solutions Manual, available for use by instructors, has been expanded; it now provides MATLAB code for numerous problems, allowing instructors to easily be able change relevant parameters.
- Reflecting the rapid advances in additive manufacturing, Chapter 20 has been thoroughly revised to include the latest technologies.

New or expanded topics in this edition are:

Chapter	Topics
Introduction	Complexity of products; definition of Technology Readiness Level and Manufacturing Readiness Level, to show the stages in product development and manufacturing at scale; case study on three-dimensional printing of guitars; expansion and update of the section on Trends in Manufacturing.
1	ISO for grain size number.
5	Second- and third-generation high-strength steels; nano-structured steels; and new case study on high-strength steels in automobiles.
6	Addition of the Hall-Héroult process for aluminum manufacture; new sections on lithium and rare earth metals; a case study on Tesla automobile design and manufacture; metamaterials.
7	Electrically conductive and semi-conductive polymers; gels and aerogels.
8	Porous ceramics; graphene; carbon and graphite foam.
10	Freeze casting.
11	Integrated computational materials engineering (ICME); machining of sand molds; new case study on a die-cast magnesium liftgate.
13	Tailor-rolled blanks and tailored coils.
15	Friction stir extrusion.
16	Expansion of hot stamping of sheet metal; camera-based forming-limit diagrams; electrically assisted forming; new case study on single-point incremental forming.
17	Expansion of powder morphology effects.
20	Additive Manufacturing: mass customization; distributed manufacturing; composite AM; projection stereolithography; continuous liquid interface production (CLIPS); new case study on AM of athletic shoes; powder bed processes; JetFusion; wire and arc AM; bioprinting; architectural applications of AM; conformal cooling; expanded section on design for AM; topology optimization; economic considerations; new case study on the implications of powder reuse.
23-24	Design considerations in machining; new case study on machining aerospace parts from monolithic aluminum.
25	Stability lobes in chatter.
26	Engineered abrasives; new case study on gear grinding with engineered abrasives.
27	Electrolytic trepanning; shaped-tube electrolytic machining.
28	Roll-to-roll printing; flexible electronics; conductive and semi-conductive inks; rotogravure, flexography, flat and rotary screen printing; self-aligned imprint lithography; flexible hybrid electronics; new case study on a flexible Arduino.
29	Photonic integrated circuits; mesoscale manufacturing.
31	Friction stir spot welding; expansion of linear friction welding.
37	Microcontrollers; cloud computing; cybersecurity; gain scheduling; cobot; design considerations.
38	Cloud storage; expansion of ERP and MES.
39	Mass customization; Internet of Things; cloud computing; MTConnect; Big Data; digital twin.
40	Life-cycle engineering; energy use in manufacturing.

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I.1 What Is Manufacturing?

As you begin to read this chapter, take a few moments to inspect various objects around you: mechanical pencil, light fixture, chair, cell phone, and computer. You soon will note that all these objects, and their numerous individual components, are made from a variety of materials and have been produced and assembled into the products you now see. You also will note that some objects, such as a paper clip, nail, spoon, and door key, are made of a single component. However, as shown in Table I.1 and Fig. I.1, the vast majority of objects around us consist of numerous individual parts that are built and assembled by a combination of processes called **manufacturing** (Fig. I.2).

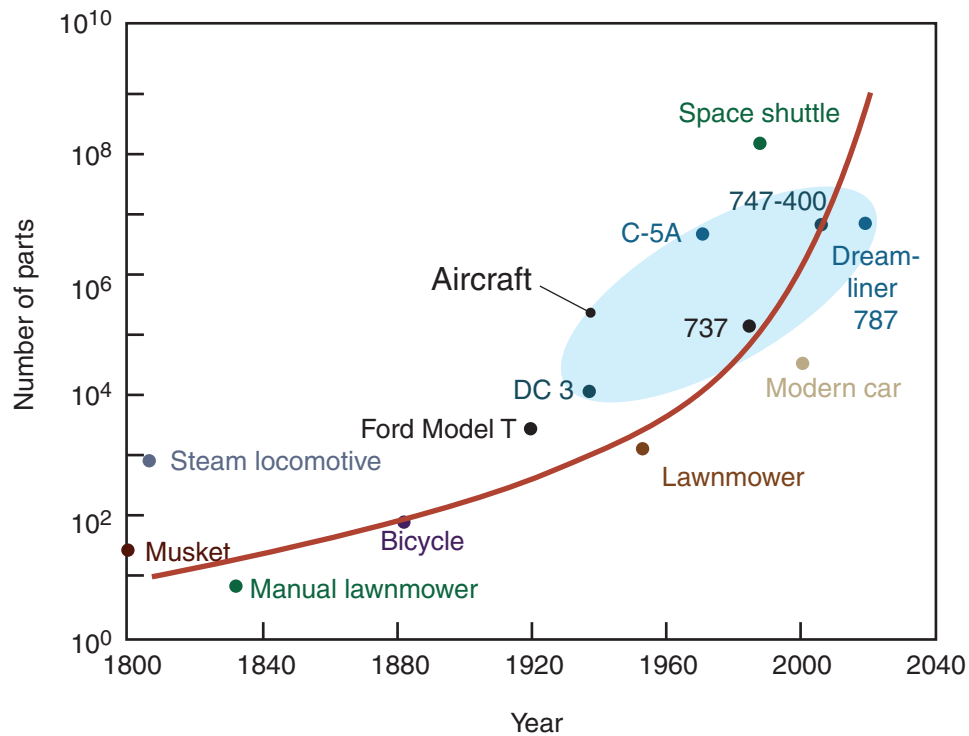


Figure I.1: Increasing complexity of products since the Industrial Revolution. *Source:* After J. Jeswiet.

The word *manufacture* first appeared in English in 1567, and is derived from the Latin *manu factus*, meaning made by hand. The word *manufacturing* first appeared in 1683, and the word *production*, which is often used interchangeably with the word *manufacturing*, first appeared sometime during the 15th century.

Manufacturing is making products. A manufactured product may, in turn, itself be used to make other products, such as (a) a large press, to shape flat sheet metal into appliances, (b) a drill, for producing holes, and (c) machinery, to produce a countless variety of individual items.

Nails, bolts, screws, nuts, paper clips, tires are *discrete products*, meaning individual items. By contrast, a spool of wire, metal or plastic tubing, and a roll of aluminum foil are *continuous products*, which are then cut into individual pieces of various lengths for specific purposes.

Because a manufactured item typically begins with raw materials, which are then subjected to a sequence of processes to make individual products, it has a certain *value*. Clay, for example, has some value as mined, but when made into pottery, electrical insulator, or cutting tool, it has *added value*. Similarly, a nail has a value over and above the cost of a short piece of wire from which it is made. Products such as computer chips, electric motors, medical implants, machine tools, and aircraft are known as *high-value-added products*.

Table I.1: Approximate Number of Parts in Products.

Common pencil	4
Rotary lawn mower	300
Grand piano	12,000
Automobile	15,000
Boeing 747-400	6,000,000



Figure I.2: John Deere tractor showing the variety of materials and processes incorporated. *Source:* Shutterstock/Nils Versemann.

A Brief History of Manufacturing. Manufacturing dates back to the period 5000 to 4000 B.C. (Table I.2). Thus, it is older than recorded history, which dates back to the Sumerians, around 3500 B.C. Primitive cave drawings, as well as markings on clay tablets and stones, needed (a) some form of a brush and some sort of pigment, as in the prehistoric cave paintings in Lascaux, France, estimated to be 16,000 years old; (b) a means of first scratching the clay tablets and then baking them, as in cuneiform scripts and pictograms of 3000 B.C.; and (c) simple tools for making incisions and carvings on the surfaces of stone, as in the hieroglyphs in ancient Egypt.

Manufacturing items for specific uses began with the production of household artifacts, typically made of wood, stone, or metal. The materials first used in making utensils and ornamental objects included gold, copper, and iron, followed by silver, lead, tin, bronze, and brass. The processing methods first employed involved mostly *casting* and *hammering*, because they were relatively easy to perform. Over the centuries, these simple processes gradually began to be developed into more and more complex operations, at increasing rates of production, and at higher levels of product quality. Note from Table I.2 that, for example, lathes for cutting screw threads already were available during the period from 1600 to 1700, but it was not until three centuries later that automatic screw machines were developed.

Although ironmaking began in about 1100 B.C. in the Middle East, a major milestone was the production of steel, in Asia, during the period 600 to 800 A.D. A wide variety of materials then began to be developed. Today, countless metallic and nonmetallic materials with unique properties are available, including *engineered materials* and other advanced materials. Among the available materials now are industrial ceramics, composite materials (often in the form of fiber reinforced plastics), and nanomaterials

Table I.2: Historical Development of Materials and Manufacturing Processes.

Period	Dates	Metals and casting	Various materials and composites	Forming and shaping	Joining	Tools, machining and manufacturing systems
Before 4000 B.C.		Gold, copper, meteoric iron	Earthenware, glazing, natural fibers	Hammering		Tools of stone, flint, wood, bone, ivory, composite tools
	4000-3000 B.C.	Copper casting, stone and metal molds, lost-wax process, silver, lead, tin, bronze		Stamping, jewelry	Soldering (Cu-Au, Cu-Pb, Pb-Sn)	Corundum (alumina, emery)
3000-2000 B.C.		Bronze casting and drawing, gold leaf	Glass beads, potter's wheel, glass vessels	Wire by slitting sheet metal	Riveting, brazing	Hoe making, hammered axes, tools for ironmaking and carpentry
	2000-1000 B.C.	Wrought iron, brass				
1000-1 B.C.		Cast iron, cast steel	Glass pressing and blowing	Stamping of coins	Forge welding of iron and steel, gluing	Improved chisels, saws, files, wood-working lathes
	1-1000 A.D.	Zinc, steel	Venetian glass	Armor, coining, forging, steel swords		Etching of armor
1000-1500		Blast furnace, type metals, casting of bells, pewter	Crystal glass	Wire drawing, gold- and silver-smith work		Sandpaper, windmill-driven saw
	1500-1600	Cast-iron cannon, tinplate	Cast plate glass, flint glass	Water power for metalworking, rolling mill for coinage strips		Hand lathe for wood
1600-1700		Permanent-mold casting, brass from copper and metallic zinc	Porcelain	Rolling (lead, gold, silver), shape rolling (lead)		Boring, turning, screw-cutting lathe, drill press
	Middle Ages: ~ 476 to 1492.					
Renaissance: 14th to 16th centuries.						
	Egypt: ~ 3100 B.C. to ~ 300 B.C. Greece: ~ 1100 B.C. to ~ 146 B.C. Roman Empire: ~ 500 B.C. to 476 A.D.					

(continues on next page)