

CONTENTS

1	THE MANUFACTURING SYSTEM	1
1.1	Evolution of the Enterprise	1
1.2	Classification of Basic Manufacturing	4
1.3	Design, Materials, and Production	7
1.4	English Metric Practice	10
	Questions	11
	Problems	11
	More Difficult Problems	12
	Practical Application	12
	Case Study: Professor Smith	12
2	NATURE AND PROPERTIES OF MATERIALS	14
2.1	Classification of Materials	14
2.2	Structure of Materials	16
2.3	Solidification of Metals and Alloys	18
2.4	Physical Characteristics of Materials	20
2.5	Engineering Properties of Materials	22
2.6	Other Methods for Material Evaluation	27
2.7	Impact and Endurance Testing	27
2.8	Composites and New Materials	31
	Questions	32
	Problems	33
	More Difficult Problems	34
	Practical Application	34
	Case Study: The Unknown Material	35
3	PRODUCTION OF FERROUS METALS	36
3.1	Production of Pig Iron	36
3.2	Furnaces for Steelmaking and Ironmaking	39
3.3	Steel Ingots and Strand Casting	44
3.4	Refining Furnaces and Vessels	47
3.5	Energy Required for Melting	50
3.6	Ferrous Metals	51
3.7	Effects of Chemical Elements on Cast Iron	57
	Questions	58
	Problems	59
	More Difficult Problems	60
	Practical Application	60
	Case Study: Melting Cost Estimate for a Foundry	61
4	PRODUCTION OF NONFERROUS METALS	62
4.1	Properties	62
4.2	Nonferrous Metals	63

4.3	Production of Aluminum	64
4.4	Production of Magnesium	65
4.5	Production of Copper	66
4.6	Production of Lead	66
4.7	Casting Nonferrous Materials	67
4.8	Wrought Alloys	69
4.9	Die-Casting Alloys	71
4.10	Continuous Casting of Aluminum	73
	Questions	74
	Problems	75
	Practical Application	75
	Case Study: Profit Analysis	75
5	FOUNDRY PROCESSES	77
5.1	Sand Castings and Molding Procedures	77
5.2	Gating System and Solidification Characteristics	82
5.3	Patterns	83
5.4	Removable Patterns	86
5.5	Sand Technology	87
5.6	Cores	92
5.7	Molding Equipment	94
5.8	Pouring and Cleaning Castings	96
	Questions	98
	Problems	99
	More Difficult Problems	100
	Practical Application	100
	Case Study: Foundry Business	100
6	CONTEMPORARY CASTING PROCESSES	101
6.1	Metal Molds	101
6.2	Precision or Investment Casting	111
6.3	Continuous Casting	119
	Questions	121
	Problems	122
	Practical Application	122
	Case Study: Water Pipe	123
7	BASIC MACHINE TOOL ELEMENTS	124
7.1	Machine Tools	124
7.2	Elements	127
7.3	Motors	131
7.4	Holding Workpieces	132
7.5	Handling Workpieces	138
7.6	Handling Tools	139
7.7	Control Systems	140
	Questions	145
	Problems	145
	More Difficult Problems	146
	Practical Application	146
	Case Study: Turbine Wheel	147

8	METAL CUTTING	148
8.1	Metal-Cutting Theory	148
8.2	Metal-Cutting Tools	156
8.3	Chip Shape and Formation	162
8.4	Coolants	165
8.5	Machinability	166
8.6	Tool Life	168
8.7	Surface Finish	171
8.8	Cutting Speeds and Feeds	173
	Questions	175
	Problems	176
	More Difficult Problems	178
	Practical Application	179
	Case Study: Advanced Job Shop	179
9	TURNING, DRILLING, BORING, AND MILLING MACHINE TOOLS	181
9.1	Lathe Group	182
9.2	Drill Press Group	191
9.3	Boring Machine Tool Group	194
9.4	Milling Machine Group	197
9.5	Transfer-Type Production Machine Group	201
	Questions	202
	Practical Application	203
	Case Study: Airframe Part, Part Number 50532	203
10	SAWING, BROACHING, SHAPING, AND PLANING	205
10.1	Metal Sawing Machines	205
10.2	Broaching	210
10.3	Shapers	216
10.4	Planers	218
	Questions	220
	Problems	221
	Practical Application	221
	Case Study: ACME Broach Company	222
11	MACHINING CUTTERS, OPERATIONS, AND PERFORMANCE	223
11.1	Cutting Tools	223
11.2	Operations	240
11.3	Performance	250
	Questions	257
	Problems	258
	More Difficult Problems	259
	Practical Application	260
	Case Study: Numerical Control Lathe Machined Forging	260
12	GRINDING AND ABRASIVE PROCESSES	263
12.1	Grinding and Abrasive Practices	263
12.2	Processes	265

12.3	Abrasives, Grinding Wheels, and Stones	278
	Questions	284
	Problems	285
	Practical Application	286
	Case Study: Karlton Grinding Company	286
13	WELDING AND JOINING PROCESSES	287
13.1	Fundamentals of a Welding System	287
13.2	Arc Welding Processes	289
13.3	Resistance Welding Processes	295
13.4	Oxyfuel Gas Welding Processes	302
13.5	Solid-State Welding Processes	305
13.6	Special Welding Processes	310
13.7	Welding Quality and Safety	314
13.8	Other Joining Processes	315
13.9	Allied Processes	318
	Questions	321
	Problems	322
	More Difficult Problems	322
	Practical Application	323
	Case Study: Welding Spacecraft Heat Shields	323
14	HOT WORKING OF METAL	324
14.1	Plastic Deformation	324
14.2	Rolling	326
14.3	Forging	328
14.4	Extrusion	335
14.5	Pipe and Tube Manufacture	336
14.6	Drawing	340
14.7	Special Methods	340
	Questions	343
	Problems	343
	Practical Application	344
	Case Study: The Yungk Company	344
15	COLD WORKING OF METAL	345
15.1	Cold Working	345
15.2	Processes	347
15.3	High-Energy Rate Forming	360
15.4	Other Methods	364
	Questions	366
	Problems	367
	Practical Application	368
	Case Study: Centrifugal Fan Fatigue Problem	368
16	PRESSWORKING AND OPERATIONS	370
16.1	Presses	370
16.2	Drive Mechanisms for Presses	380
16.3	Feed Mechanisms	381

16.4	Operations	382
16.5	Efficient Use of Materials	392
	Questions	394
	Problems	394
	More Difficult Problems	396
	Practical Application	397
	Case Study: Twelve-Ounce Beverage Container Company	397
17	HEAT TREATING	399
17.1	Iron–Iron Carbide Diagram	399
17.2	Grain Size	404
17.3	Isothermal Transformation Diagrams	405
17.4	Hardening	406
17.5	Tempering	409
17.6	Annealing	412
17.7	Normalizing and Spheroidizing	413
17.8	Surface Hardening	414
17.9	Hardening Nonferrous Materials	418
17.10	Furnaces for Heat Treating	419
	Questions	421
	Problems	421
	Practical Application	422
	Case Study: Heat Treating	422
18	PLASTIC MATERIALS AND PROCESSES	423
18.1	Raw Materials and Properties	423
18.2	Thermosetting Compounds	426
18.3	Thermoplastic Compounds	428
18.4	Processing Plastics	431
18.5	Processing Thermosets	432
18.6	Processing Thermoplastics	437
18.7	Other Processes	445
18.8	Design Fundamentals	447
	Questions	449
	Problems	450
	More Difficult Problems	450
	Practical Application	451
	Case Study: The General Plastics Company	451
19	ELECTRONIC FABRICATION	453
19.1	Components and Definitions	453
19.2	From Components to Products	457
19.3	The Soldering System	458
19.4	Solder Joint Design	464
19.5	Thermal Characteristics	467
19.6	Electromagnetic Interference and Electrostatic Discharges	469
19.7	Cleaning Process	470
19.8	Emerging Packaging Technologies	472
	Questions	474
	Problems	475

More Difficult Problems	476
Practical Application	476
Case Study: The Hot Chip Problem	477
20 NONTRADITIONAL PROCESSES AND POWDER METALLURGY	478
20.1 Special Machining Processes	478
20.2 Temperature Machining	486
20.3 Chemical Energy	488
20.4 Electroforming	492
20.5 Metal Spraying	494
20.6 Powder Metallurgy	496
Questions	507
Problems	508
More Difficult Problems	508
Practical Application	508
Case Study: Electrochemical Machining	509
21 THREAD AND GEAR WORKING	510
21.1 Screw Threads	510
21.2 Processes for Making Threads	513
21.3 Gears	520
21.4 Processes for Making Gears	524
21.5 Finishing Operations for Gears	532
Questions	532
Problems	533
Practical Application	534
Case Study: Lotus Gear Works	534
22 FINISH PROCESSES	535
22.1 Mechanical Surface Preparation	535
22.2 Chemical Surface Preparation	539
22.3 Plating Procedures	543
22.4 Metal Deposition Design Considerations	547
22.5 Thickness Testing	549
22.6 Other Metallic Coatings	551
Questions	554
Problems	554
More Difficult Problems	555
Practical Application	555
Case Study: Strike One	555
23 OPERATIONS PLANNING	556
23.1 Business Objectives	556
23.2 Systems Analysis	557
23.3 Operations Sheet Preparation	558
23.4 Information	560
23.5 Sequence of Operations	560
23.6 Pinion Operations Sheet	561

23.7	Welded Steel Assembly Operations Sheet	564
23.8	Trends	566
	Questions	567
	Problems	567
	More Difficult Problems	570
	Practical Application	570
	Case Study: Super Snap Ring	571
24	GEOMETRIC DIMENSIONING AND TOLERANCING	572
24.1	Dimension and Tolerance	572
24.2	Symbols	573
24.3	Applications	577
24.4	CAD and CAM	582
24.5	Appropriate Tolerances	582
	Questions	585
	Problems	585
	More Difficult Problems	587
	Practical Application	588
	Case Study: Minimum Cost Tolerances for Gear Train	588
25	TOOL DESIGN	590
25.1	Practices	590
25.2	Workholding	593
25.3	Fixtures and Jigs	594
25.4	Pressworking Tools	596
25.5	Welding Tools	601
25.6	Molding Tools	602
25.7	Inspection Gages	604
25.8	Stereolithography	608
	Questions	608
	Problems	608
	More Difficult Problems	612
	Practical Application	614
	Case Study: Oil Filter Wrench	614
26	METROLOGY AND TESTING	615
26.1	Fundamentals of Metrology	615
26.2	Linear Measurements	618
26.3	Angular Measurements	622
26.4	Surface Measurements	623
26.5	Electrical Measurements	627
26.6	Gages and Other Measurements	628
26.7	Nondestructive Inspection	635
26.8	Statistics and Uncertainty	638
	Questions	640
	Problems	640
	More Difficult Problems	641
	Practical Application	641
	Case Study: The Swing Frequency	642

27	QUALITY SYSTEMS	643
27.1	Quality Systems and Process Improvement	643
27.2	Process Variation	646
27.3	Control Charts for Variable Data	648
27.4	Control Charts for Attribute Data	653
27.5	Process Capability Analysis	655
27.6	Statistical Design of Experiments	657
27.7	Reliability Theory	660
	Questions	662
	Problems	662
	More Difficult Problems	663
	Practical Application	665
	Case Study: U Chart for Control	665
28	COMPUTER NUMERICAL CONTROL SYSTEMS	666
28.1	Types of CNC Systems	666
28.2	Evolution of CNC Machine Tools	667
28.3	Types of Controllers	668
28.4	CNC Operational Sequence	671
28.5	Rectangular Coordinates	673
28.6	Program Formatting and Coding	675
28.7	Types of Programming and Interpolation	679
28.8	High-Level Languages	681
28.9	Emergent Control Methods	682
	Questions	683
	Problems	684
	More Difficult Problems	684
	Practical Application	685
	Case Study: Drilled Plate	685
29	PROCESS AUTOMATION	687
29.1	Simulation	687
29.2	Automation	688
29.3	Robots	697
29.4	Group Technology	707
29.5	Flexible Manufacturing Systems	709
29.6	Other Production Systems	711
29.7	Economic Considerations	716
	Questions	717
	Problems	718
	More Difficult Problems	718
	Practical Application	719
	Case Study: The Round Plate Company	719
30	OPERATOR-MACHINE SYSTEMS	720
30.1	Operator-Machine Systems Structure	720
30.2	Ergonomics	721
30.3	Designing Ergonomic Tools	723
30.4	Redesigning Workstations	734

30.5	Job Analysis	737
30.6	Systems to Measure Injury Frequency	740
30.7	Impact of Intelligent Systems	742
	Questions	744
	Problems	744
	More Difficult Problems	745
	Practical Application	746
	Case Study: CTD Costs and Frequency in Electronic Parts Manufacturing	746
31	COST ESTIMATING	747
31.1	Classical Metal Cutting Cost Analysis	747
31.2	Industrial Cost Estimating Practices	753
31.3	Estimating Setup and Cycle Time	754
31.4	Material Estimating	756
	Questions	759
	Problems	759
	More Difficult Problems	761
	Practical Application	761
	Case Study: Pinion	761
	Bibliography	762
	Photo Credits	763
	Index	766

1.1 EVOLUTION OF THE ENTERPRISE

Manufacture is derived from the Latin, *manu factus*, or literally "made by hand." But the power of the hand tool is limited. Domesticated animals and water power from the water wheel were steps in the evolution. Harnessing water power provided an opportunity for the development of power-driven machine tools and manufacturing. In the United States the small shops were often located near a pond that had a waterwheel. In fact, water-driven machine tools were used to build the first practical steam engine, Wilkinson's boring machine, which was used for machining the cylinders of James Watt's steam engine, which was invented in 1776. This is generally accepted to be the beginning of the Industrial Revolution. This power source could be located wherever it was needed for work.

Motive Power

With the availability of power and its transmission by overhead power belts, other machine tool developments followed. Note Figure 1.1, which is a woodcut illustration of