

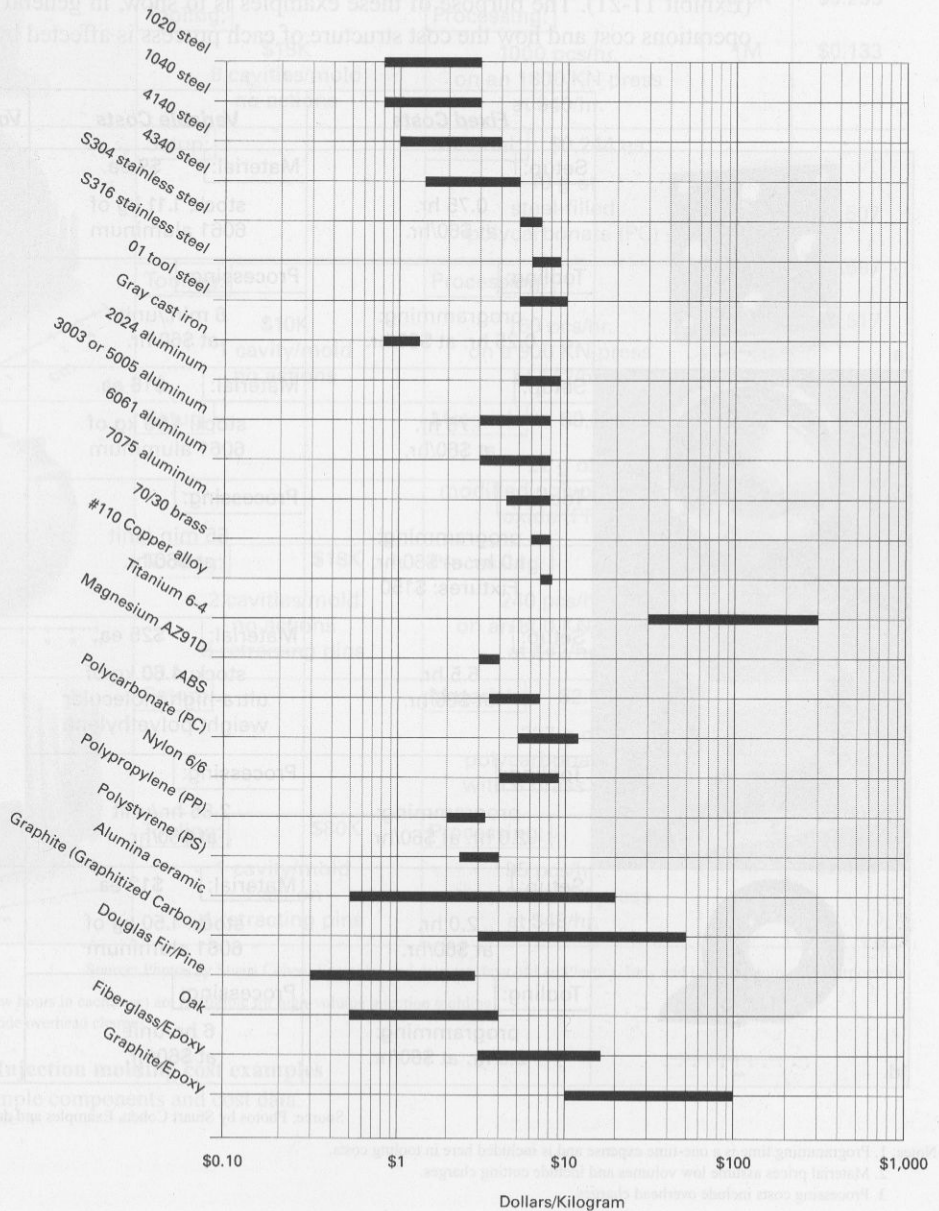
## Appendix A

## Materials Costs

**EXHIBIT  
11-17**

Range of costs for common engineering materials. Price ranges shown correspond to various grades and forms of each material, purchased in bulk quantities (2007 prices).

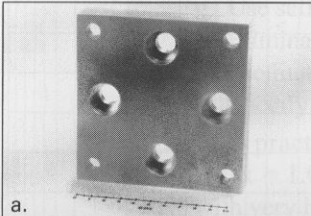
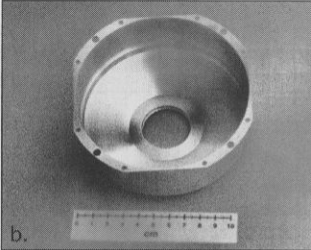
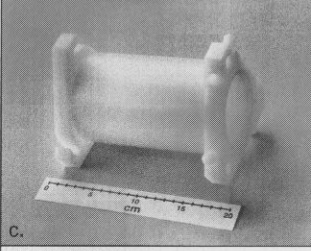
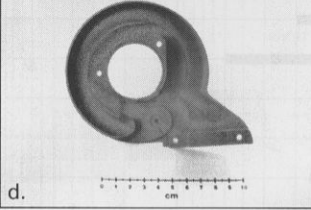
Source: Adapted from David G. Ullman, *The Mechanical Design Process*, third edition, McGraw-Hill, New York, 2003



Appendix B

Component Manufacturing Costs

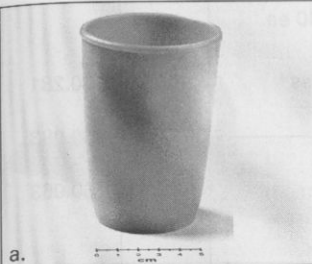
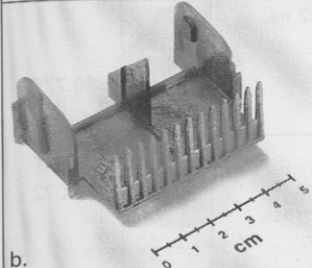
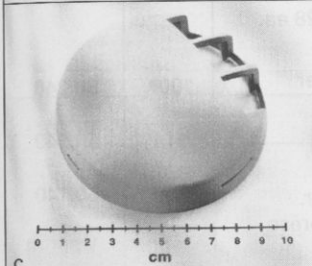
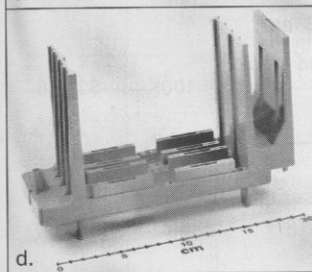
The exhibits in this appendix show example components and their cost data for computer-numerical control (CNC) machining (Exhibit 11-18), injection molding (Exhibit 11-19), progressive die stamping (Exhibit 11-20), and sand casting and investment casting (Exhibit 11-21). The purpose of these examples is to show, in general terms, what typical operations cost and how the cost structure of each process is affected by part complexity.

	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 a.	Setup:	Material: \$9 ea.	1 10 100	\$75.00 \$21.00 \$15.50
	0.75 hr. at \$60/hr.	stock: 1.11 kg of 6061 aluminum		
	Tooling:	Processing:		
	programming: 0.25 hr. at \$60/hr.	6 min./unit at \$60/hr.		
 b.	Setup:	Material: \$16 ea.	1 10 100	\$386.00 \$102.50 \$74.15
	1.75 hr. at \$60/hr.	stock: 1.96 kg of 6061 aluminum		
	Tooling:	Processing:		
	programming: 1.0 hr. at \$60/hr. Fixtures: \$150	55 min./unit at \$60/hr.		
 c.	Setup:	Material: \$25 ea.	1 10 100	\$646.00 \$241.00 \$200.50
	5.5 hr. at \$60/hr.	stock: 4.60 kg of ultra-high molecular weight polyethylene		
	Tooling:	Processing:		
	programming: 2.0 hr. at \$60/hr.	2.85 hr./unit at \$60/hr.		
 d.	Setup:	Material: \$12 ea.	1 10 100	\$612.00 \$396.00 \$374.40
	2.0 hr. at \$60/hr.	stock: 1.50 kg of 6061 aluminum		
	Tooling:	Processing:		
	programming: 2.0 hr. at \$60/hr.	6 hr./unit at \$60/hr.		

Source: Photos by Stuart Cohen. Examples and data courtesy of Ramco, Inc.

Notes: 1. Programming time is a one-time expense and is included here in tooling costs.  
2. Material prices assume low volumes and include cutting charges.  
3. Processing costs include overhead charges.

EXHIBIT 11-18 CNC machining cost examples  
CNC machining example components and cost data.

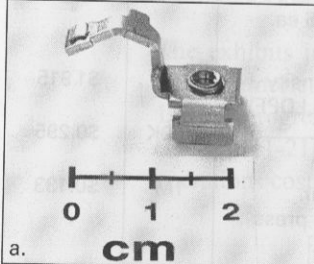
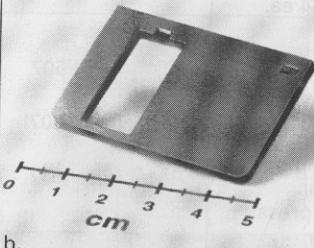
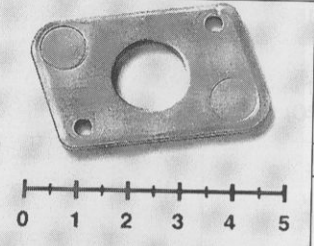
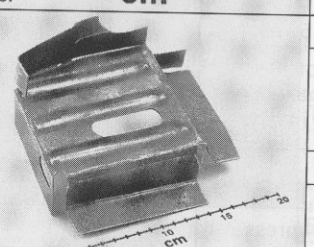
	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 a.	Setup:	Material: \$0.075 ea.	10K 100K 1M	\$1.915 \$0.295 \$0.133
		45 g of linear low density polyethylene (LLDPE)		
	Tooling:	Processing:		
	\$18K 8 cavities/mold no actions	1000 pcs/hr. on an 1800 KN press at \$40/hr.		
 b.	Setup:	Material: \$0.244 ea.	10K 100K 1M	\$1.507 \$0.607 \$0.517
		10 g of steel-filled polycarbonate (PC)		
	Tooling:	Processing:		
	\$10K 1 cavity/mold no actions	160 pcs/hr. on a 900 KN press at \$42/hr.		
 c.	Setup:	Material: \$0.15 ea.	10K 100K 1M	\$2.125 \$0.505 \$0.343
		22 g of modified polyphenylene oxide (PPO)		
	Tooling:	Processing:		
	\$18K 2 cavities/mold no actions 3 retracting pins	240 pcs/hr. on an 800 KN press at \$42/hr.		
 d.	Setup:	Material: \$2.58 ea.	10K 100K 1M	\$11.085 \$3.885 \$3.165
		227 g of polycarbonate (PC) with 8 brass inserts		
	Tooling:	Processing:		
	\$80K 1 cavity/mold 1 action 4 retracting pins	95 pcs/hr. on a 2700 KN press at \$48/hr.		

Source: Photos by Stuart Cohen. Examples and data courtesy of Lee Plastics, Inc., and Digital Equipment Corporation

Notes: 1. Setup costs (only a few hours in each case) are negligible for high-volume injection molding.  
2. Processing costs include overhead charges.

EXHIBIT 11-19 Injection molding cost examples  
Injection molding example components and cost data.



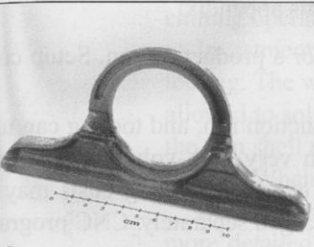

	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 a.	Setup:	Material: \$0.040 ea. 2.2g 70/30 Brass	100K	\$0.281
	Tooling:	Processing:	1M	\$0.083
	\$22K	3000 pcs/hr. on a 550 KN press at \$63/hr.	10M	\$0.063
 b.	Setup:	Material: \$0.032 ea. 3.5 g 304 SST	100K	\$0.775
	Tooling:	Processing:	1M	\$0.136
	\$71K	4300 pcs/hr. on a 550 KN press at \$140/hr.	10M	\$0.072
 c.	Setup:	Material: \$0.128 ea. 19.2 g 102 copper	100K	\$0.248
	Tooling:	Processing:	1M	\$0.149
	\$11K	4800 pcs/hr. on a 650 KN press at \$50/hr.	10M	\$0.140
 d.	Setup:	Material: \$0.28 ea. 341 g galvanized steel	100K	\$2.516
	Tooling:	Processing:	1M	\$0.761
	\$195K	700 pcs/hr. on a 1000 KN press at \$200/hr.	10M	\$0.585

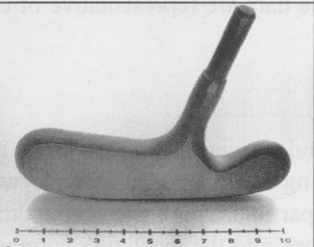
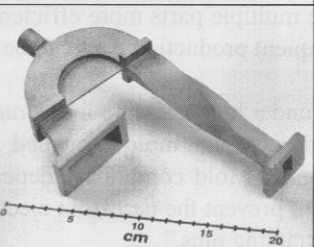
Source: Photos by Stuart Cohen. Examples and data courtesy of Brainin Advance Industries and other sources

- Notes: 1. Setup costs (only a few hours in each case) are negligible for high-volume stamping.  
2. Material weights represent the finished stampings. Material costs include scrap.  
3. Hourly processing costs are not only driven by press size, but also can include ancillary processing equipment, such as in-die tapping.  
4. Processing costs include overhead charges.

EXHIBIT 11-20 Stamping cost examples

Volume progressive die stamping example components and cost data.

	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 a.	Setup:	Material: \$0.53 ea. 570 g of gray cast iron	10	\$180.91
	Tooling:	Processing:	100	\$18.91
	\$1.8K 8 impressions/pattern no core	120 pcs/hr. at \$46/hr.	1000	\$2.71
 b.	Setup:	Material: \$2.42 ea. 2,600 g of gray cast iron	10	\$243.95
	Tooling:	Processing:	100	\$27.95
	\$2.4K 2 impressions/pattern 1 core	30 pcs/hr. at \$46/hr.	1000	\$6.35

	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 c.	Setup:	Material: \$0.713 ea. 260 g of yellow brass	10	\$163.21
	Tooling:	Processing:	100	\$28.21
	\$1.5K no cores	4 pcs/hr. at \$50/hr.	1000	\$14.71
 d.	Setup:	Material: \$0.395 ea. 180 g of 712 aluminum	10	\$750.40
	Tooling:	Processing:	100	\$120.40
	\$7K 3 cores	1 pc/hr. at \$50/hr.	1000	\$57.40

Source: Photos by Stuart Cohen. Examples and data courtesy of Cumberland Foundry Co., Inc. (sand casting), and Castronics, Inc. (investment casting)

- Notes: 1. Setup is not generally charged in costing.  
2. Processing costs include overhead charges.

EXHIBIT 11-21 Casting cost examples

Sand casting (top) and investment casting (bottom) example components and cost data.

Terminology

The following terminology applies to all of the tables in this appendix:

- **Setup** is the work required to prepare the equipment for a production run. Setup costs are charged for each run.
- **Tooling costs** are incurred in advance of the first production run, and tooling can usually be reused for later production runs. However, in very high-volume production runs, tooling wears out and therefore is a recurring expense. Tooling costs may be spread over the entire production volume or may be charged separately. CNC programming time is generally also a one-time expense, like a tooling cost.
- **Material types** are listed for each part. Material weights and costs include processing scrap and waste.
- **Processing costs** vary with the type of manufacturing equipment used and include charges for both machine time and labor.

While fixed costs (setup and tooling) are sometimes billed separately from material and processing costs, for these examples, fixed costs are spread over the production volume shown. Unit costs are calculated as

Total unit cost =  $\frac{\text{Setup costs} + \text{Tooling costs}}{\text{Volume}}$  + Variable costs

The cost rates given include overhead charges, so these data are representative of custom components purchased from suppliers.

Description of Processes

CNC machining includes computer-controlled milling and turning processes. CNC machines are highly flexible due to automatic tool-changing mechanisms, multiple work axes, and programmable computer control. To produce a particular part, a machinist must first program the cutting tool trajectories and tool selections into the machine's computer. Also, fixtures or other tooling may be utilized to produce multiple parts more efficiently. Once the program is written and fixtures are made, subsequent production runs can be set up much more quickly.

Injection molding is the process of forcing hot plastic under high pressure into a mold, where it cools and solidifies. When the part is sufficiently cool, the mold is opened, the part is ejected, the mold closes, and the cycle begins again. Mold complexity depends highly on the part geometry; undercuts (features that would prevent the part from ejecting out of the mold) are achieved using mold "actions" or "retracting pins."

Progressive die stamping is the process of passing a sheet or strip of metal through a set of dies to cut and/or form it to a desired size and shape. While some stampings require only cutting, formed stampings are made by bending and stretching the metal beyond its yield point, thereby causing permanent deformation.

Sand castings are created by forming a sand mold from master patterns (tooling in the shape of the final part). Special binders are mixed with the sand to allow the sand to retain shape when packed around the pattern to create a single-use mold. Internal cavities in a casting can be created using additional sand cores inside the outer mold. Molten metal

is then poured into the mold where the metal cools and solidifies. Once cool, the sand is broken off to reveal the metal casting. Sand castings generally require subsequent machining operations to create finished components.

Investment castings are made by first creating a temporary wax pattern, using master tooling. The wax pattern is then dipped or immersed in plaster or ceramic slurry which is allowed to solidify. The form is then heated, melting out the wax, and leaving behind only the thin shell as a mold. Molten metal is then poured into the mold, where it cools and solidifies. When the metal is cool, the mold is broken off to reveal the metal part.

Detailed process descriptions for the above and numerous other processes, as well as more detailed cost estimating techniques, can be found in the reference books listed for this chapter.

EXHIBIT 11-23

Appendix D		Cost Structures		Cost Calculation	
Type of Firm	Part	No. of Unique Parts	No. of Fasteners	Material Cost	Processing Cost
Electromechanical products (machines, instruments, etc.)	Fastest Part	48	120	1.20	1.20
Traditional cost structures (machines, instruments, etc.)	Slowest Part	48	120	1.20	1.20
Progressive die stamping (machines, instruments, etc.)	Fastest Part	48	120	1.20	1.20
Heavy equipment components (machines, instruments, etc.)	Fastest Part	48	120	1.20	1.20
Total		48	120	1.20	1.20
Electromechanical products (machines, instruments, etc.)	Slowest Part	48	120	1.20	1.20
Traditional cost structures (machines, instruments, etc.)	Fastest Part	48	120	1.20	1.20
Progressive die stamping (machines, instruments, etc.)	Fastest Part	48	120	1.20	1.20
Heavy equipment components (machines, instruments, etc.)	Fastest Part	48	120	1.20	1.20
Total		48	120	1.20	1.20

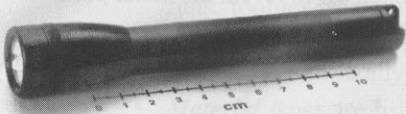
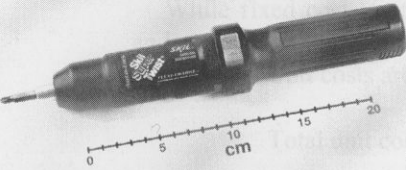

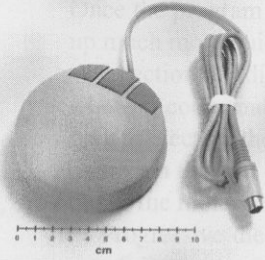
EXHIBIT 11-24

Assembly cost for common products. Obtained using Boothroyd Dewhurst, Inc. DFA Software.

EXHIBIT 11-25




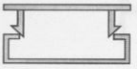
Assembly Costs

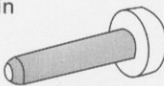

Product	Part Data	Assembly Times (Seconds)	
		No. of Parts	Total
	No. of Parts	16	125.7
	No. of Unique Parts	12	9.7
	No. of Fasteners	0	2.9
	No. of Parts	34	186.5
	No. of Unique Parts	25	10.7
	No. of Fasteners	5	2.6
	No. of Parts	49	266.0
	No. of Unique Parts	43	14.0
	No. of Fasteners	5	3.5
	No. of Parts	56/17*	277.0/138.0*
	No. of Unique Parts	44/12*	8.0/8.0*
	No. of Fasteners	0/0*	0.75/3.0*

Source: Photos by Stuart Cohen. Data obtained by using Boothroyd Dewhurst Inc. DFA software

\*Data for the mouse are given as: total components (including electronic/mechanical components only).  
Notes: 1. This table gives manual assembly times, which can be converted to assembly costs using applicable labor rates.  
2. Assembly times shown include times for individual part handling and insertion, as well as other operations such as subassembly handling and insertion, reorientations, and heat riveting.

EXHIBIT 11-22 Assembly costs  
Assembly data for common products. Obtained using Boothroyd Dewhurst Inc. DFA Software.

Component	Time (Seconds)		
	Min	Max	Avg
Screw 	7.5	13.1	10.3
Snap-fit 	3.5	8.0	5.9

Component	Time (Seconds)		
	Min	Max	Avg
Pin 	3.1	10.1	6.6
Spring 	2.6	14.0	8.3

Source: Manual assembly tables in Boothroyd and Dewhurst, 1989

EXHIBIT 11-23 Typical handling and insertion times for common components.

Appendix D

Cost Structures

Type of Firm	Cost Calculation
Electromechanical products manufacturer (Traditional cost structure)	Cost = (113%) × (Materials cost) + (360%) × (Direct labor cost)
Precision valve manufacturer (Activity-based cost structure)	Cost = (108%) × [(Direct labor cost) + (Setup labor cost) + (160%) × (Materials cost) + (\$27.80) × (Machine hours) + (\$2,000.00) × (Number of shipments)]
Heavy equipment component manufacturer (Activity-based cost structure)	Cost = (110%) × (Materials cost) + (109%) × [(211%) × (Direct labor cost) + (\$16.71) × (Machine hours) + (\$33.76) × (Setup hours) + (\$114.27) × (Number of production orders) + (\$19.42) × (Number of material handling loads) + (\$487.00) × (Number of new parts added to the system)]

Sources, top to bottom: Unpublished company source; Harvard Business School cases: Destin Brass Products Co., 9-190-089, and John Deere Component Works, 9-187-107

Notes: 1. This table shows total costs per customer order.  
2. Materials costs include costs of raw materials and purchased components.

EXHIBIT 11-24 Typical cost structures for manufacturing firms.