**TABLE 13.10**
**Determination of Unit Cost for Three Processes Based on Cost Model in Sec. 13.3.5**

| Cost Element | Low Pressure Permanent Mold | Injection Molding | Squeeze Casting |
|---|---|---|---|
| Material cost, $C_M$ ($/lb) | 0.60 | 1.80 | 0.60 |
| Fraction of process that is scrap, $f$ | 0.1 | 0.05 | 0.1 |
| Mass of part, $m$ (lb) | 8.6 | 4.1 | 8.6 |
| **$C_1$ see Eq. (13.4) unit cost** | **$5.73** | **$7.77** | **$5.73** |
| Labor cost, $C_L$ ($/h) | 25.00 | 25.00 | 25.00 |
| Production rate, $n$, (units/h) | 38 | 45 | 30 |
| **$C_2$ see Eq. (13.5) unit cost** | **$0.66** | **$0.55** | **$0.83** |
| Tooling cost, $C_T$ ($/set) | 80,000 | 70,000 | 80,000 |
| Total production run, $n$ (units) | 500,000 | 500,000 | 500,000 |
| Tooling life, $n_t$ (units) | 100,000 | 200,000 | 100,000 |
| Sets of tooling required, $k$ | 5 × 2 | 3 × 2 | 5 × 2 |
| **$C_3$ see Eq. (13.6) unit cost** | **$1.60** | **$0.84** | **$1.60** |
| Capital cost, $C_C$ ($) | 100,000 × 2 | 500,000 × 2 | 200,000 |
| Capital write-off time, $t_{wo}$ (yrs) | 5 | 5 | 5 |
| Load fraction, L (fraction) | 1 | 1 | 1 |
| Load sharing fraction, $q$ | 1 | 1 | 1 |
| **$C_4$ see Eq. (13.7) unit cost** | **$0.17** | **$0.74** | **$0.44** |
| Factory overhead, $C_{OH}$ ($/h) | 60 | 60 | 60 |
| Production rate, $\dot{n}$ (units/h) | 38 | 45 | 30 |
| **$C_5$ see Eq. (13.8) unit cost** | **$1.58** | **$1.33** | **$2.00** |
| **Total unit cost = $C_1 + C_2 + C_3 + C_4 + C_5$** | **$9.74** | **$11.23** | **$10.60** |

Low-pressure permanent mold casting is the obvious choice for producing the fan hub and blades. The only reason for rejecting this process would be if it was not possible to maintain required dimensions or tolerance, or if the castings contained porosity. Squeeze casting would be an attractive alternative, since the addition of mechanically induced compressive stresses would result in less distortion of the metal on cooling, and the ability to hold tighter tolerances for a relatively small increase in unit cost. 13

## 13.5
## DESIGN FOR MANUFACTURE (DFM)

For the past 20 years engineers have seen a large amount of effort devoted to the integration of design and manufacture, with the goals of reducing manufacturing cost and improving product quality. The processes and procedures that have been developed have become known as *design for manufacture* or design for manufacturability (DFM). Associated with this is the closely related area of *design for assembly* (DFA).

The field is often simply described by the abbreviation DFM/DFA or DFMA. DFMA methods should be applied during the embodiment stage of design.

Design for manufacture represents an awareness of the importance of design as the time for thoughtful consideration of all steps of production. To achieve the goals of DFM requires a concurrent engineering team approach (Sec. 2.4.4) in which appropriate representatives from manufacturing, including outside suppliers, are members of the design team from the start.

### 13.5.1 DFM Guidelines

DFM guidelines are statements of good design practice that have been empirically derived from years of experience.[19] Using these guidelines helps narrow the range of possibilities so that the mass of detail that must be considered is within the capability of the designer.

1. **Minimize total number of parts:** Eliminating parts results in great savings. A part that is eliminated costs nothing to make, assemble, move, store, clean, inspect, rework, or service. A part is a good candidate for elimination if there is no need for relative motion, no need for subsequent adjustment between parts, and no need for materials to be different. However, part reduction should not go so far that it adds cost because the remaining parts become too heavy or complex.

   The best way to eliminate parts is to make minimum part count a requirement of the design at the conceptual stage of design. Combining two or more parts into an integral design architecture is another approach. Plastic parts are particularly well suited for integral design.[20] Fasteners are often prime targets for part reduction. Another advantage of making parts from plastics is the opportunity to use snap-fits instead of screws, Fig. 13.14a.[21]
2. **Standardize components:** Costs are minimized and quality is enhanced when standard commercially available components are used in design. The benefits also occur when a company standardizes on a minimum number of part designs (sizes, materials, processes) that are produced internally in its factories. The life and reliability of standard components may have already been established, so cost reduction comes through quantity discounts, elimination of design effort, avoidance of equipment and tooling costs, and better inventory control.
3. **Use common parts across product lines:** It is good business sense to use parts in more than one product. Specify the same materials, parts, and subassemblies in each product as much as possible. This provides economies of scale that drive down unit cost and simplify operator training and process control. Product

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19. H.W. Stoll, *Appl. Mech. Rev,* Vol. 39, No. 9, pp. 1356–64, 1986; J.R. Bralla, *Design for Manufacturability Handbook,* 2d ed., McGraw-Hill, New York, 1999; D.M. Anderson, *Design for Manufacturability,*, 2d ed., CIM Press, Cambria, CA, 2001.

20. W. Chow, *Cost Reduction in Product Design,* chap. 5, Van Nostrand Reinhold, New York, 1978.

21. P.R. Bonnenberger, *The First Snap-Fit Handbook,* 2d ed., Hanser Gardener Publications Cincinnati, OH, 2005.

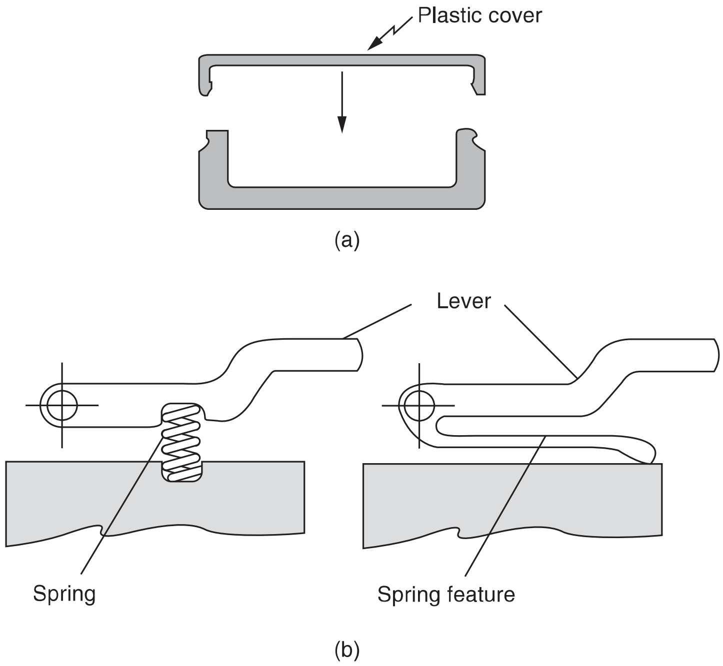


**FIGURE 13.14**
Some examples of applying DFM. (a) This product utilizes snap-fit principles to attach the cover, eliminating the need for screw fasteners. Since the cover is molded from plastic material and because of the taper of the snap-fit elements, it also illustrates *compliance*. (b) This illustrates a multifunctional part. By incorporating a spring function in the lever, the need for a separate coil spring is eliminated.

data management (PDM) systems can be used to facilitate retrieval of similar designs.

4. **Standardize design features.**Standardizing on design features like drilled hole sizes, screw thread types, and bend radii minimizes the number of tools that must be maintained in the tool room. This reduces manufacturing cost.
5. **Aim to keep designs functional and simple:** Achieving functionality is paramount, but don't specify more performance than is needed. It is not good engineering to specify a heat-treated alloy steel when a plain carbon steel will achieve the performance with a little bit more careful analysis. When adding features to the design of a component, have a firm reason for the need. The product with the fewest parts, the least intricate shapes, the fewer precision adjustments, and the lowest number of manufacturing steps will be the least costly to manufacture. Also, the simplest design will usually be the most reliable and the easiest to maintain.
6. **Design parts to be multifunctional:** A good way to minimize part count is to design such that parts can fulfill more than one function, leading to integral architecture. For example, a part might serve as both a structural member and a spring, Fig. 13.14*b*. The part might be designed to provide a guiding, aligning, or self-fixturing feature in assembly. This rule can cancel out guideline 5 and break guideline 7 if it is carried too far.

7. **Design parts for ease of fabrication:** As discussed in Chap. 11, the least costly material that satisfies the functional requirements should be chosen. It is often the case that materials with higher strength have poorer workability or fabricability. Thus, one pays more for a higher-strength material, and it also costs more to process it into the required shape. Since machining to shape tends to be costly, manufacturing processes that produce the part to *near net shape* are preferred whenever possible so as to eliminate or minimize machining.

   It is important to be able to visualize the steps that a machine operator will use to make a part so that you can minimize the manufacturing operations needed to make the part. For example, clamping a part before machining is a time-consuming activity, so design to minimize the number of times the operator will be required to reorient the part in the machine to complete the machining task. Reclamping also is a major source of geometric errors. Consider the needs for the use of fixtures and provide large solid mounting surfaces and parallel clamping surfaces.

   Rough evaluations for how easily specific materials can be processed by different manufacturing methods are given in Fig. 13.17. Guidelines for specific processes are given in Secs. 13.11 to 13.19.
8. **Avoid excessively tight tolerances:** Tolerances must be set with great care. Specifying tolerances that are tighter than needed results in increased cost; recall Fig. 13.13. These come about from the need for secondary finishing operations like grinding, honing, and lapping, from the cost of building extra precision into the tooling, from longer operating cycles because the operator is taking finer cuts, and from the need for more skilled workers. Before selecting a manufacturing process, be sure that it is capable of producing the needed tolerance and surface finish.

   As a designer, it is important to maintain your credibility with manufacturing concerning tolerances. If in doubt that a tolerance can be achieved in production, always communicate with manufacturing experts. Never give a verbal agreement to manufacturing that they can loosen a tolerance without documentation and making the change on the part drawing. Also, be careful about how the statement for blanket tolerances on the drawing is worded and might be misinterpreted by manufacturing.
9. **Minimize secondary and finishing operations:** Minimize secondary operations such as heat treatment, machining, and joining and avoid finishing operations such as deburring, painting, plating, and polishing. Use only when there is a functional reason for doing so. Machine a surface only when the functionality requires it or if it is needed for aesthetic purposes.
10. **Utilize the special characteristics of processes:** Be alert to the special design features that many processes provide. For example, molded polymers can be provided with "built-in" color, as opposed to metals that need to be painted or plated. Aluminum extrusions can be made in intricate cross sections that can then be cut to short lengths to provide parts. Powder-metal parts can be made with controlled porosity that provides self-lubricating bearings.



These rules are becoming the norm in every engineering design course and in engineering practice.

### 13.5.2 Specific Design Rules

A number of DFM rules for design, more specific than the preceding guidelines, have been developed.[22]

1. Space holes in machined, cast, molded, or stamped parts so they can be made in one operation without tooling weakness. This means that there is a limit on how close holes may be spaced due to strength in the thin section between holes.
2. Avoid generalized statements on drawings, like "polish this surface" or "toolmarks not permitted," which are difficult for manufacturing personnel to interpret. Notes on engineering drawings must be specific and unambiguous.
3. Dimensions should be made from specific surfaces or points on the part, not from points in space. This greatly facilitates the making of gages and fixtures. The use of GD&T methods makes this point moot.
4. Dimensions should all be from a single datum surface rather than from a variety of points to avoid overlap of tolerances.
5. The design should aim for minimum weight consistent with strength and stiffness requirements. While material costs are minimized by this criterion, there also will usually be a reduction in labor and tooling costs.
6. Whenever possible, design to use general-purpose tooling rather than special dies, form cutters, and similar tools. An exception is high-volume production where special tooling may be more cost-effective.
7. Use generous fillets and radii on castings and on molded, formed, and machined parts.
8. Parts should be designed so that as many operations as possible can be performed without requiring repositioning. This promotes accuracy and minimizes handling.

It is valuable to have manufacturing engineers and specialists involved in design decision making so that these guidelines and others they bring can inform the process.

## 13.6
## DESIGN FOR ASSEMBLY (DFA)



Once parts are manufactured, they need to be assembled into subassemblies and products. The assembly process consists of two operations, *handling*, which involves grasping, orienting, and positioning, followed by *insertion and fastening*. There are three types of assembly, classified by the level of automation. In *manual assembly* a human operator at a workstation reaches and grasps a part from a tray, and then moves, orients, and pre-positions the part for insertion. The operator then places the parts together and fastens them, often with a power tool. In *automatic assembly,* handling is accomplished with a parts feeder, like a vibratory bowl, that feeds the cor-

22. J.R. Bralla, *Design for Manufacturability Handbook,* 2d ed., McGraw-Hill, New York, 1999.

rectly oriented parts for insertion to an automatic workhead, which in turn inserts the part.[23] In *robotic assembly,* the handling and insertion of the part is done by a robot arm under computer control.

The cost of assembly is determined by the number of parts in the assembly and the ease with which the parts can be handled, inserted, and fastened. Design can have a strong influence in both areas. Reduction in the number of parts can be achieved by elimination of parts (e.g., replacing screws and washers with snap or press fits, and by combining several parts into a single component). Ease of handling and insertion is achieved by designing so that the parts cannot become tangled or nested in each other, and by designing with symmetry in mind. Parts that do not require end-to-end orientation prior to insertion, as a screw does, should be used if possible. Parts with complete rotational symmetry around the axis of insertion, like a washer, are best. When using automatic handling it is better to make a part highly asymmetric if it cannot be made symmetrical.

For ease of insertion, a part should be made with chamfers or recesses for ease of alignment, and clearances should be generous to reduce the resistance to assembly. Self-locating features are important, as is providing unobstructed vision and room for hand access. Figure 13.15 illustrates some of these points.

### 13.6.1 DFA Guidelines

The guidelines for design for assembly can be grouped into three classes: general, handling, and insertion.

**General Guidelines**

1. **Minimize the total number of parts:** A part that is not required by the design is a part that does not need to be assembled. Go through the list of parts in the assembly and identify those parts that are essential for the proper functioning of the product. All others are candidates for elimination. The criteria for an *essential part*, also called a theoretical part, are:
   - The part must exhibit motion relative to another part that is declared essential.
   - There is a fundamental reason that the part be made from a material different from all other parts.
   - It would not be possible to assemble or disassemble the other parts unless this part is separate, that is it is an essential connection between parts.
   - Maintenance of the product may require disassembly and replacement of a part.
   - Parts used only for fastening or connecting other parts are prime candidates for elimination.

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23. G. Boothroyd, *Assembly Automation and Product Design,* 2d ed., CRC Press, Boca Raton, FL, 2005; "Quality Control and Assembly," *Tool and Manufacturing Engineers Handbook*, Vol. 4, Society of Manufacturing Engineers, Dearborn, MI 1987.

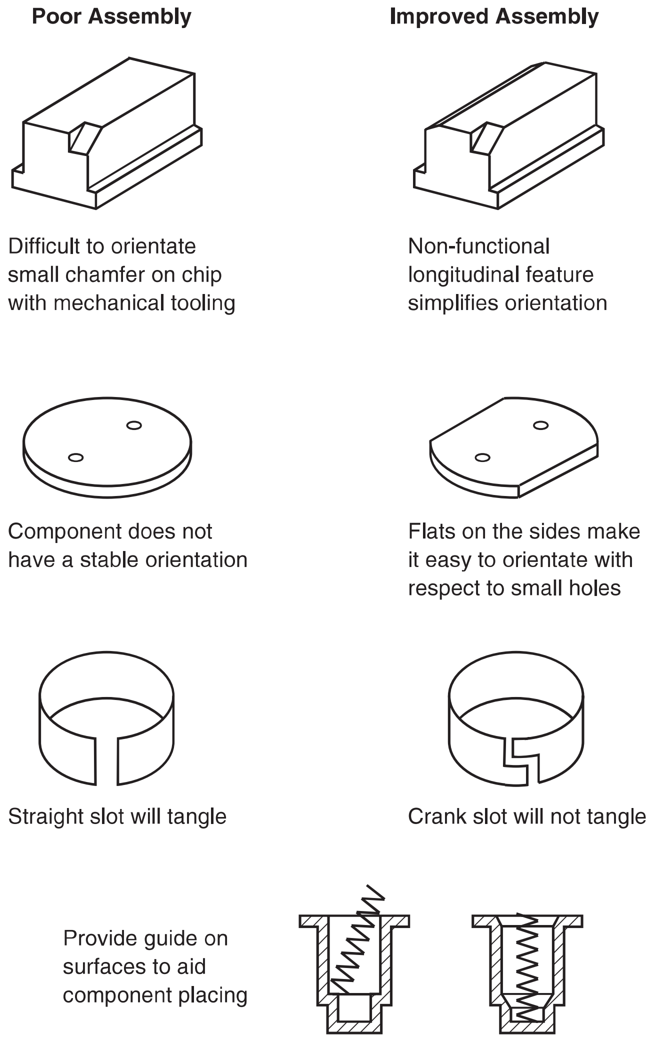


**FIGURE 13.15**
Some design features that improve assembly.

Designs can be evaluated for efficiency of assembly with Eq. (13.10), where the time taken to assemble a "theoretical" part is taken as 3 seconds.[24]

$$\text{Design assembly efficiency} = \frac{3\times \text{ "theoretical" minimum number of parts}}{\text{total assembly time for all parts}} \tag{13.10}$$

A theoretical part is one that cannot be eliminated from the design because it is needed for functionality. Typical first designs have assembly efficiencies of 5 to 10 percent, while after DFA analysis it is typically around 20 to 30 percent.

2. **Minimize the assembly surfaces:** Simplify the design so that fewer surfaces need to be prepared in assembly, and all work on one surface is completed before moving to the next one.

24. For small parts such as those found in household and electronic products, the assembly time runs from 2 to 10 seconds. On an automobile assembly line, times of 45 to 60 seconds are more typical.

3. **Use subassemblies:** Subassemblies can provide economies in assembly since there are fewer interfaces in final assembly. Subassemblies can also be built and tested elsewhere and brought to the final assembly area. When subassemblies are purchased they should be delivered fully assembled and tested. Products made from subassemblies are easier to repair by replacing the defective subassembly.
4. **Mistake-proof the design and assembly:** An important goal in design for assembly is to ensure that the assembly process is unambiguous so that the operators cannot make mistakes in assembling the components. Components should be designed so that they can only be assembled one way. The way to orient the part in grasping it should be obvious. It should not be capable of being assembled in the reverse direction. Orientation notches, asymmetrical holes, and stops in assembly fixtures are common ways to mistake-proof the assembly process. For more on mistake-proofing, see Sec. 13.8.

**Guidelines for Handling**

5. **Avoid separate fasteners or minimize fastener costs:** Fasteners may amount to only 5 percent of the material cost of a product, but the labor they require for proper handling in assembly can reach 75 percent of the assembly costs. The use of screws in assembly is expensive. Snap fits should be used whenever possible. When the design permits, use fewer large fasteners rather than several small ones. Costs associated with fasteners can be minimized by standardizing on a few types and sizes of fasteners, fastener tools, and fastener torque settings. When a product is assembled with a single type of screw fastener it is possible to use auto-feed power screwdrivers.
6. **Minimize handling in assembly:** Parts should be designed to make the required position for insertion or joining easy to achieve. Since the number of positions required in assembly equates to increased equipment expense and greater risk of defects, quality parts should be made as symmetrical as their function will allow. Orientation can be assisted by design features that help to guide and locate parts in the proper position. Parts that are to be handled by robots should have a flat, smooth top surface for vacuum grippers, or an inner hole for spearing, or a cylindrical outer surface for gripper pickup.



**Guidelines for Insertion**

7. **Minimize assembly direction:** All products should be designed so that they can be assembled from one direction. Rotation of an assembly requires extra time and motion and may require additional transfer stations and fixtures. The best situation in assembly is when parts are added in a top-down manner to create a z-axis stack.
8. **Provide unobstructed access for parts and tools:** Not only must the part be designed to fit in its prescribed location, but there must be an adequate assembly path for the part to be moved to this location. This also includes room for the operator's arm and tools, which in addition to screwdrivers, could include wrenches or welding torches. If a worker has to go through contortions to perform an assembly operation, productivity and possibly product quality will suffer after a few hours of work.

9. **Maximize compliance in assembly:** Excessive assembly force may be required when parts are not identical or perfectly made. Allowance for this should be made in the product design. Designed-in compliance features include the use of generous tapers, chamfers, and radii. If possible, one of the components of the product can be designed as the part to which other parts are added (part base) and as the assembly fixture. This may require design features that are not needed for the product function.

## 13.7 ROLE OF STANDARDIZATION IN DFMA

In Section 1.7 the important role of codes and standards in engineering design was introduced. There the emphasis was on the role of standards in protecting public safety and assisting the designer in performing high-quality work. In this section we extend these ideas about standardization to show the important role that part standardization can play in DFMA.

Part proliferation is an endemic problem in manufacturing unless steps are taken to prevent it from happening. One large automotive manufacturer found that in one model line alone it used 110 different radiators, 1200 types of floor carpet, and 5000 different fasteners. Reducing the variety of parts that achieve the same function can have many benefits to the product development enterprise. Firm numbers on the cost of part proliferation are difficult to obtain, but estimates are that about half of manufacturing overhead costs are related to managing too many part numbers.

### 13.7.1 Benefits of Standardization

The benefits of standardization occur in four areas: cost reduction, quality improvement, production flexibility, and manufacturing responsiveness.[25] The specifics of benefits in each area are outlined here.

#### Cost Reduction

- **Purchasing costs.** Standardization of parts and the subsequent reduction in part numbers[26] will result in large savings in procurement costs in outsourcing because parts will be bought in larger quantities. This allows for quantity discounts, flexible delivery schedules, and less work for the purchasing department.
- **Reduce costs through raw material standardization.** Cost for in-house production of parts can be reduced if raw materials can be standardized to a single size of bar stock, tubing, and sheet metal. Also, metal casting and plastic molding operations can each be limited to a single material. These standardization efforts allow for increased use of automated equipment with a minimum of cost for tool and fixture changing and setup.

25. D.M. Anderson, *Design for Manufacturability,* 2d ed., Chap. 5 CIM Press, Cambria, CA, 2001.
26. A part number is the identification for a part (often a drawing number) and is not to be confused with the number of parts.

- **Feature standardization.** Part features such as drilled, reamed, or threaded holes and bend radii in sheet metal all require special tools. Unless there is a dedicated machine for each size, the tools need to be changed for different dimensions, with the corresponding setup charge. Designers often specify an arbitrary hole size, when a standard size would do just as well. If the specification of radii in lathe turning or milling is not standardized it can cause a requirement for the shop to maintain a large inventory of cutting tools.
- **Reduction of inventory and floor space requirements.** The preceding cost reduction tactics assist in decreasing inventory costs either as incoming parts inventory, or the work-in-progress inventory, through fewer machine setups. Standardization makes building-on-demand more of a possibility, which will greatly decrease finished goods inventory. Reducing inventory has the advantage of reducing the required factory floor space. All of these issues, reduction of inventory and floor space, tooling costs, and purchasing and other administrative costs result in a decrease in overhead costs.

**Quality Improvement**

- **Product quality.** Having fewer parts of a given type greatly reduces the chance of using the wrong part in an assembly.
- **Prequalification of parts.** The use of standard parts means that there is much greater cumulative experience with using the particular part. This means that standard parts can be prequalified for use in a new product without the requirement for extensive testing.
- **Supplier reduction means improved quality.** Standardization of parts means there will be fewer outside suppliers of parts. Those suppliers remaining should be those with a record of producing quality parts. Giving more business to fewer suppliers will be an incentive for developing stronger supplier relationships.

**Production Flexibility**

- **Material logistics.** The flow of parts within the plant will be easier with fewer parts to order, receive, stock, issue, assemble, test, and reorder.
- **Reliable delivery of standard low-cost parts.** These parts can be restocked directly to points of use in the plant by parts suppliers using long-term purchase agreements, much as food is delivered to a supermarket. This reduces overhead costs for purchasing and materials handling.
- **Flexible manufacturing.** Eliminating setup operations allows products to be made in any batch size. This allows the products to be made to order or to *mass customize* the product. This eliminates finished goods inventory and lets the plant make only the products for which it has an order.



**Manufacturing Responsiveness**

- **Parts availability.** Fewer part types used in greater volume will mean less chance of running out of parts and delaying production.
- **Quicker supplier deliveries.** Standardization of parts and materials should speed up deliveries. Suppliers will have the standard tools and materials in their inventory.

- **Financially stronger suppliers.** Part suppliers to OEMs have seen their profit margins narrow, and many have gone out of business. With larger volume orders and fewer part types to make, they can rationalize their business model, simplify their supply chain management, and reduce overhead costs. This will give them the resources to improve the quality and efficiency of their operations.

While the benefits from standardization seem very compelling, it may not always be the best course of action. For example, the compromises required by standardization may restrict the design and marketing options in undesirable ways. Stoll[27] presents pros and cons about part standardization.

### 13.7.2 Achieving Part Standardization

Many engineers do not realize that regardless of the cost of a part, there is real cost in ordering, shipping, receiving, inspecting, warehousing, and delivering the part to where it will be used on the assembly line. Thus, it is just as important to be concerned with standardization of inexpensive parts like fasteners, washers, and resistors as it is with more intricate molded parts. Young engineers need to be made aware of the importance of part standardization, and, they should understand that they are not free to make arbitrary decisions when sizing parts. Early in their careers they should be made aware of the company standard part list, and if one does not exist they should work with their colleagues to develop one.[28]

A common misconception is that the way to achieve a minimum-cost design is to create a minimum-weight design. Certainly this may be true in aircraft and spacecraft design where weight is very important, but for most product design this design philosophy should not be followed if it means using nonstandard parts. The most economical approach is to select the next larger *standard size* of motor, pump, or angle iron to achieve adequate strength or functionality. Special sizes are justified only in very special situations.

A common reason for the existence of part duplication is that the designer is not aware of the existence of an identical part. Even if she knows of its existence, it may be more difficult to find the part number and part drawing than it is to create a new part. This issue is discussed in Sec. 13.7.3.



### 13.7.3 Group Technology

*Group technology* (GT) is a methodology in which similar parts are grouped together in order to take advantage of their common characteristics. Parts are grouped into *part families* in terms of commonality of design features (see Fig. 13.6), as well as manufacturing processes and processing steps. Table 13.11 lists typical design and manufacturing characteristics that would be considered.

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27. H.W. Stoll, *Product Design Methods and Practices,* Chaps. 9 & 10, Marcel Dekker, New York, 1999.
28. See D.M. Anderson, op. cit, for a detailed description of how to generate a standard part list.

**TABLE 13.11**
**Design and Man ufacturing Characteristics that Are Typically Considered in GT Classification**

| Design Characteristics of Part | | Manufacturing Characteristics of Part | |
|---|---|---|---|
| External shape | Part function | External shape | Annual production |
| Internal shape | Type of material | Major dimensions | Tooling and fixtures used |
| Major dimensions | Tolerances | Length/diameter ratio | Sequence of operations |
| Length/diameter ratio | Surface finish | Primary process used | Tolerances |
| Shape of raw material | Heat treatment | Secondary processes | Surface finish |

### Benefits of Group Technology

- GT makes possible standardization of part design and elimination of part duplication. Since only about 20 percent of design is original design, new designs can be developed using previous similar designs, with a great saving in cost and time.
- By being able to access the previous work of the designer and the process planner, new and less experienced engineers can quickly benefit from that experience.
- Process plans for making families of parts can be standardized and retained for future use. Therefore, setup times are reduced and more consistent quality is obtained. Also, since the tools and fixtures are often shared in making a family of parts, unit costs are reduced.
- With production data aggregated in this way, cost estimates based on past experience can be made more easily, and with greater precision.

Another advantage of group technology addresses the trend among consumers for greater variety in products. This has pushed most consumer products from being mass produced products to batch production. Batch manufacturing facilities are typically organized in a *functional layout*, in which processing machines are arranged by common type, that is, lathes are arranged together in a common area, as are milling machines, grinders, and so on. Parts are moved from area to area as the sequence of machining operations dictates. The result is delays because of the need for tooling changes as part types change, or the machine stands idle waiting for a new batch of parts to be delivered. A functional layout is hardly a satisfactory arrangement for batch production.



A much better arrangement is using a *manufacturing cell layout.* This arrangement exploits the similarities provided by a part family. All the equipment necessary to produce a family of parts is grouped into a cell. For example, a cell could be a lineup of a lathe, milling machine, drill press, and cylindrical grinder, or it could be a CNC machining center that is equipped to do all of these machining operations, in turn, on a single computer-controlled machine. Using a cell layout, the part is transferred with minimum movement and delay from one unit of the cell to another. The machines are kept busy because GT analysis has insured that the part mix among the products made in the factory provides an adequate volume of work to make the cell layout economically viable.

### Part Classification

Group technology depends on the ability to classify parts into families. At a superficial level this appears relatively easy to do, but to gain the real benefits of GT requires much experience and hard work. Classification of parts can be approached on four levels.

1. **Experience-based judgment.** The easiest approach is to assemble a team of experienced design engineers and process planners to classify parts into families based on part shape and knowledge of the sequence of processing steps used to make the part. This approach is limited in its search capabilities, and it may not assure an optimum processing sequence.
2. **Production flow analysis (PFA).** Production flow analysis uses the sequence of operations to make a part, as obtained from factory routing sheets or computer-aided process planning. Parts that are made by identical operations form a family. This is done by creating a matrix of part numbers (rows) versus machine numbers/operation numbers. The rows and columns are rearranged, often with computer assistance, until parts that use the same process operations are identified by being grouped together in the matrix. These parts are then candidates for being incorporated into a manufacturing cell.

   The PFA method quickly ends up with very large, unwieldy matrices. A practical upper limit is several hundred parts and 20 different machines. Also, the method has difficulty if past process routing has not been done consistently.
3. **Classification and coding.** The previous two methods are chiefly aimed at improving manufacturing operations. Classification and coding is a more formal activity that is aimed at DFMA. The designer assigns a *part code* that includes such factors as basic shape, like in Fig. 13.6, external shape features, internal features, flat surfaces, holes, gear teeth, material, surface properties, manufacturing process, and operation sequences. As of yet, there is no universally applicable or accepted coding system. Some GT systems employ a code of up to 30 digits.
4. **Engineering database.** With the advent of large relational databases, many companies are building their own GT systems directly applicable to their own line of products. All information found on an engineering drawing plus processing information can be archived.



Software on the market does this in one of three ways:

- The designer sketches the shape of the part on the computer screen and the computer searches for all part drawings that resemble this shape.
- The software provides the capability to rapidly browse the library of hundreds of drawings, and the designer flags those that look interesting.
- The designer annotates the part drawing with text descriptors such as the part characteristics shown in Table 13.11. Then the computer can be asked, for example, to retrieve all part drawings with an L/D ratio between certain limits, or retrieve a combination of descriptors.

Determining part classification is an active area of research, stimulated by the widespread use of CAD. The power of computational algorithms combined with