# MECHANICAL EQUIPMENT DESIGN FOR SIMPLICITY

**Ronald G. Watson, Ellen M. Theis, and Robert S. Janek**

Mechanical product design can be greatly enhanced by following the principles of design for simplicity (DFS). Properly applied, DFS results in lower material cost, fewer mechanical parts and drawings, fewer suppliers, less inventory and storage space, and substantially easier assembly. This yields higher-reliability products at lower cost with more value to our customers. Field service personnel and customers also find that these products are much easier to use and that they get to the market sooner. DFS employs multifunctional teams early in the product realization process. Following straightforward design and assembly practices and drawing on their diverse backgrounds, these teams use brainstorming and concurrent engineering techniques to create the desired product design. Telephones with 50 percent fewer parts, minicomputers and printers with 40 percent fewer parts, and complete digital PBX systems with 25 percent fewer parts are typical results. The process is powerful, the results are impressive, and the future is bright! Once a design team has employed the process, its members often refuse to accept products that were developed without it.

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## Introduction

Mechanical design for simplicity is an essential and extremely important step in the overall design for manufacturability (DFM) process. (See Panel 1 for a list of acronyms used in this paper.) DFS techniques must be employed early in the product realization process (PRP) to reap the maximum benefits from this method. A design team is assembled after the marketing and product management organizations generate the product needs and initial product requirements. The makeup of the DFS team is critical. Key members are from the design

**Panel 1. Acronyms and Abbreviations in This Paper**

| | |
|---|---|
| AT | assembly time; the time required to assemble all pieces and subassemblies in the factory |
| CAD | computer-aided design |
| DFM | design for manufacturability; the overall process of optimizing a product design relative to manufacturing requirements |
| DFS | design for simplicity; a method utilizing concurrent engineering techniques to reduce the number of parts in an assembly and to minimize assembly time |
| DFX | design for *X*, where *X* stands for manufacturability, installability, reliability, safety, serviceability, and other downstream considerations beyond performance and functionality |
| *E* | assembly efficiency; a DFS term used to indicate ease of assembly; $E = (N \times 100)/\mathrm{AT}$ |
| *N* | number of parts; total number of parts in an assembly |
| PBX | private branch exchange; a switching machine that provides custom telephone services to a business |
| PRP | product realization process |
| TMNP | theoretical minimum number of parts; minimum number of parts required to perform the function and meet service capability |

and manufacturing groups. Members from marketing, product management, purchasing, installation, field/customer support, and other functions often play important roles in the DFS process. The essence of DFS is to eliminate unnecessary piece parts in the design and to simplify the basic assembly process; a detailed description of the method is provided later.

The principal DFS group attributes required are an understanding of the product's required functionality, the ability to design a system to meet those requirements, and knowledge of assembly methods and the manufacturing process. However, expert knowledge in other areas such as purchasing, troubleshooting and servicing, and installation often adds critical support to the team. A DFS team can be trained in less than 2 days and is often generating DFS products by the end of the second day. Since the method employs an iterative process, experience is required to understand when an optimum design is reached. Given enough time and resources, a team could design an entire computer with only a few parts! Such a design would clearly not be optimum in today's marketplace. On the other end of the spectrum lie designs that have been developed without any DFS/DFM or concurrent engineering techniques and were "thrown over the fence" from the development organization to the manufacturing organization. Design changes and product "churning" are typical in this mode of operation. Very often, a large number of subassemblies and parts result that are difficult to assemble and certainly increase purchasing, documentation, storage, and overall product costs.

An optimum design zone exists that includes the minimum total parts and assembly costs, yet also meets the critical design-to-manufacture interval. A computer with only a few parts may be easy to assemble and would minimize purchasing, storage, and servicing efforts, but the development time, tooling costs, and engineering effort would be prohibitive. The throw-it-over-the-fence design may minimize engineering, tooling, and per-part costs, but the final cost to the company would also be prohibitively high. The key is to meet the customer's expectation (features, cost, quality, schedule), and DFS can help engineers do it.

Figures 1 and 2 illustrate the notion of an optimum design zone for typical electronic assemblies with 25 to 500 parts or subassemblies. Many of AT&T's current products fall in this range. Unit part cost will increase as each part (subassembly) is made more complex. Total parts cost usually is minimum when the total engineering, tooling, and complexity are matched with the current manufacturing technologies and production

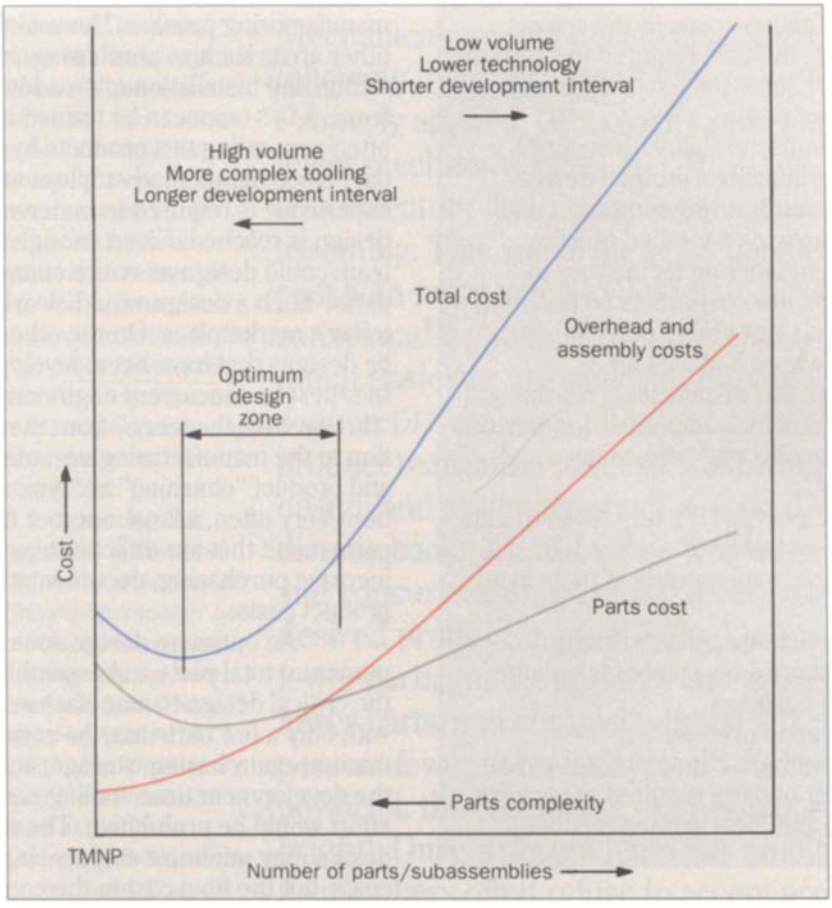



**Figure 1. Cost/complexity chart of low-end electronic and mechanical systems (25 to 50 parts) in high-volume production. In the optimum design zone, the larger tooling cost is offset by the higher volume, the increase in development interval is small because of the simple system design, and no major technology breakthrough is required to approach the theoretical minimum number of parts.**



volume. Assembly cost increases with more parts (operations) and increases sharply if the parts are more difficult to assemble (e.g., with screws, washers, or welding). More complex individual parts often require a high volume of manufacture to recoup initial investment in engineering, tooling, and significant technology breakthroughs. Less complex parts (e.g., off the shelf) are much less expensive, but this is often offset by higher assembly and overhead expenses. Overall product reliability and serviceability are improved usually at the expense of the longer development intervals. Improved reliability and serviceability result when there are fewer parts in a design that can fail or be assembled incorrectly.

Figure 1 shows the cost/complexity relationship for a high-volume electronic assembly containing approximately 25 to 50 standard parts. Assembly and miscellaneous costs will increase as more individual parts are required to be purchased, inventoried, and assembled. Total parts cost, however, will probably be minimized somewhere close to, but higher than, the

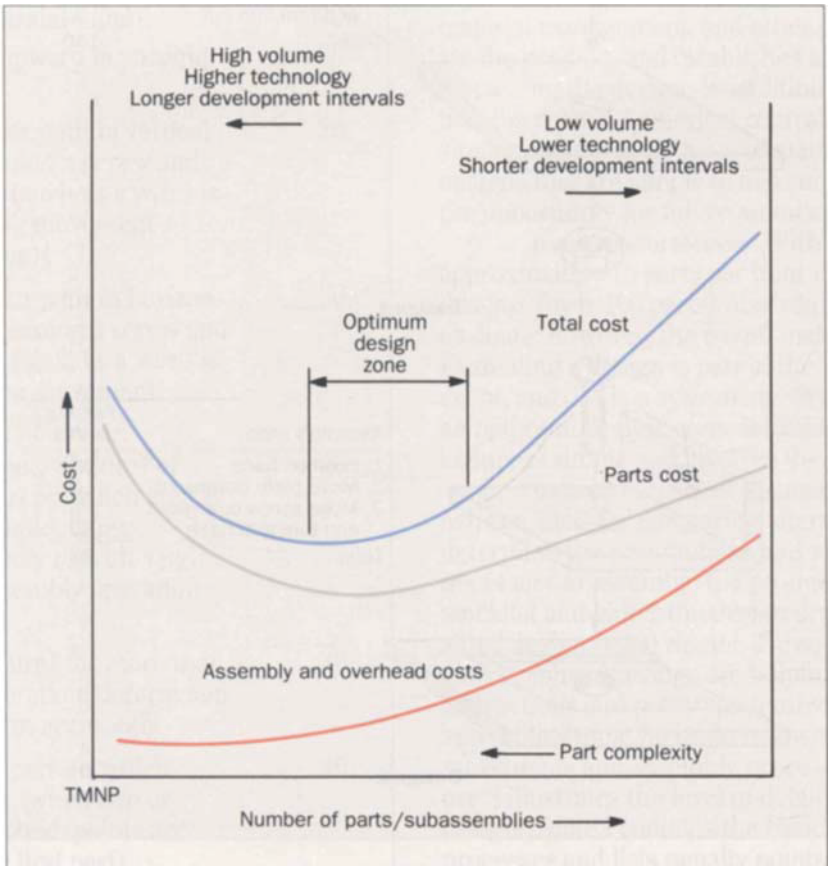


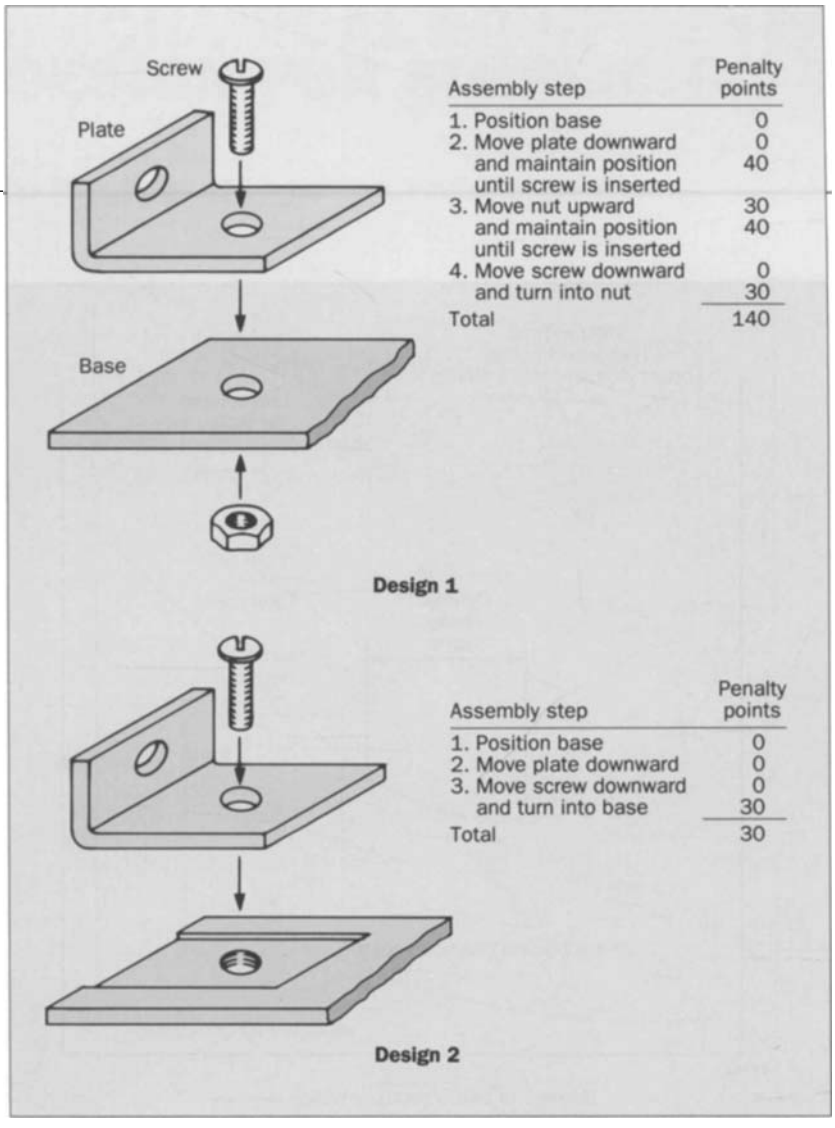

**Figure 2. Cost/complexity chart for larger electronic and mechanical systems (about 500 parts) in medium-volume production (5000 to 10,000 units per year). The optimum design zone is characterized by moderate tooling cost, strategic technology, and a moderate development interval.**

theoretical minimum number of parts (TMNP), which represents the least amount of parts necessary to create the product.

Figure 2 shows the cost/complexity relationship for a medium-volume midsize electronic assembly (up to 500 parts). In this case, the product design team will probably arrive at a production design whose parts count is considerably greater than its TMNP. This design will be a result of available technology, subassembly and part development intervals, higher tooling costs not offset by volume, and the higher level of complexity of the system design. The optimum design zone will be nearer the middle of the cost/complexity chart.

The challenge for the DFS product team is to determine the acceptable or optimum design zone for the product. The minimum total product cost point is not always selected for the production design because the allowable time-to-market interval often drives the point to the right in Figures 1 and 2. Ways to minimize the impact of using more complex parts are:

- Reuse existing technology.
- Allow for parallel design and development effort.




| Assembly step | Penalty points |
|---|---|
| 1. Position base | 0 |
| 2. Move plate downward | 0 |
| and maintain position | 40 |
| until screw is inserted | |
| 3. Move nut upward | 30 |
| and maintain position | 40 |
| until screw is inserted | |
| 4. Move screw downward | 0 |
| and turn into nut | 30 |
| Total | 140 |

| Assembly step | Penalty points |
|---|---|
| 1. Position base | 0 |
| 2. Move plate downward | 0 |
| 3. Move screw downward | 0 |
| and turn into base | 30 |
| Total | 30 |

**Figure 3. An example of the detail needed to evaluate a design with DFS. The self-locating feature and inclusion of threads in design 2 eliminates fixturing (position-maintaining) operations, which are costly.**



- Freeze all designs early and do not allow changes.
- Work with your vendors (have them participate in DFS sessions) as early as possible and let them develop as much of the complex technology as prudent.

Once the product team has agreed on an acceptable design target by using the DFS technique outlined in this paper, rigorous concurrent engineering design activity is needed to maximize product design robustness and to reduce the variation of the manufacturing process. Applied properly, robust design techniques can economically reduce a product's functional variation in the customer's environment (maximize customer delight).[1]

The DFS process provides that opportunity.

### The DFS Method

The formal DFS process offers many benefits. It is a simple analytical method for evaluating a design and its impact on downstream processes early in the PRP. It identifies areas for improvement at the beginning, thereby reducing changes late in the design cycle when they are more costly. DFS helps the designer, in conjunction with other team members, to move methodically toward an optimum design by comparing alternative designs. In addition, engineers can estimate the manufacturing costs for the design early in the design process.

DFS encourages formation of a product team (from design, manufacturing, marketing, service,

**Table I. Assembly Operation Elements and Penalty Points[3]**

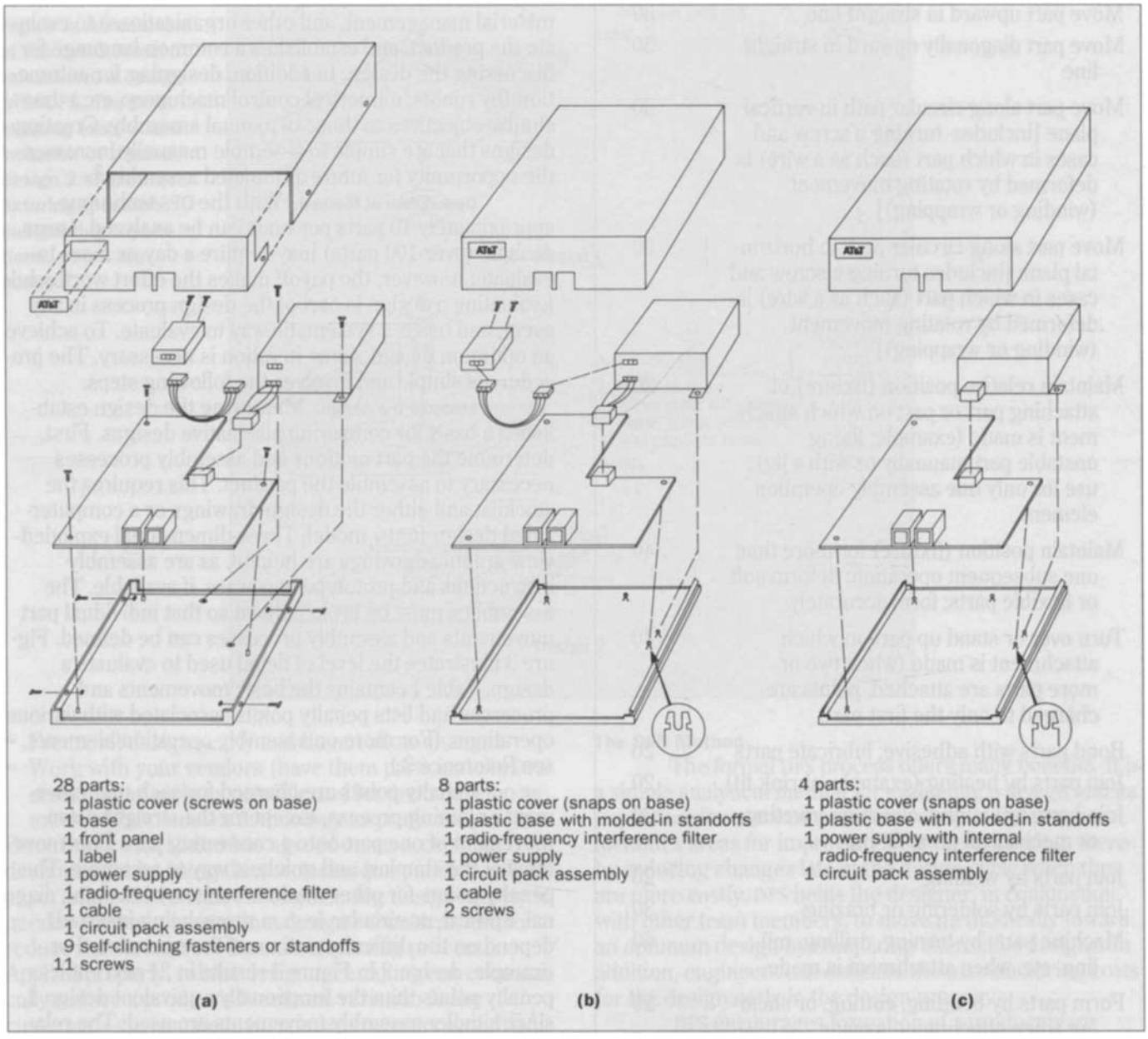
| Operation | Penalty points |
|---|---|
| Move part downward in straight line | 0 |
| Move part horizontally in straight line | 20 |
| Move part diagonally downward in straight line | 30 |
| Move part upward in straight line | 30 |
| Move part diagonally upward in straight line | 30 |
| Move part along circular path in vertical plane [includes turning a screw and cases in which part (such as a wire) is deformed by rotating movement (winding or wrapping)] | 30 |
| Move part along circular path in horizontal plane [includes turning a screw and cases in which part (such as a wire) is deformed by rotating movement (winding or wrapping)] | 30 |
| Maintain relative position (fixture) of attaching part or part on which attachment is made (example: fixing unstable part manually or with a jig); use for only one assembly operation element | 20 |
| Maintain position (fixture) for more than one subsequent operation; deform soft or flexible parts; form accurately | 40 |
| Turn over or stand up part on which attachment is made (when two or more parts are attached, points are charged to only the first part) | 40 |
| Bond parts with adhesive; lubricate parts | 20 |
| Join parts by heating (example: shrink fit) | 20 |
| Join parts by staking, clinching, riveting, or mechanical press fitting | 20 |
| Join parts by welding | 20 |
| Join parts by soldering or brazing | 30 |
| Machine parts by turning, drilling, milling, etc. when attachment is made | 60 |
| Form parts by bending, cutting, or shearing when attachment is made | 20 |

material management, and other organizations) to evaluate the product, and establishes a common language for discussing the design. In addition, designing for automation (by robots, numerical control machinery, etc.) has similar objectives to those of manual assembly. Creating designs that are simple to assemble manually increases the opportunity for future automated assembly.[2]

**Description of Method.** With the DFS technique, approximately 10 parts per hour can be analyzed. Large designs (over 100 parts) may require a day or more to evaluate; however, the payoff makes the effort worthwhile. Evaluating a design is part of the design process in any event, and DFS is a systematic way to evaluate. To achieve an optimum design, some iteration is necessary. The procedure is simple and involves the following steps.

Measure the design. Measuring the design establishes a basis for comparing alternative designs. First, determine the part motions and assembly processes necessary to assemble the product. This requires the stocklist and either the design drawings or a computer-aided design (CAD) model. Three-dimensional exploded-view graphic drawings are helpful, as are assembly instructions and prototype hardware, if available. The assemblies must be broken down so that individual part movements and assembly processes can be defined. Figure 3 illustrates the level of detail used to evaluate a design. Table I contains the basic movements and processes and lists penalty points associated with various operations. (For more on assembly operation elements, see Reference 3.)

Penalty points are charged for each part movement or joining process, except for the straight-down movement of one part onto a connecting part. This movement is the simplest and quickest way to assemble. The penalty points for other motions such as horizontal, diagonal, upward, or circular (e.g., a screw being inserted) depend on the difficulty or time of the operation. For example, design 2 in Figure 3 results in 21 percent less penalty points than the functionally equivalent design 1, since simpler assembly movements are used. The relative cost of assembly operations in Table I can be calcu-


28 parts:
1 plastic cover (screws on base)
1 base
1 front panel
1 label
1 power supply
1 radio-frequency interference filter
1 cable
1 circuit pack assembly
9 self-clinching fasteners or standoffs
11 screws
(a)
8 parts:
1 plastic cover (snaps on base)
1 plastic base with molded-in standoffs
1 radio-frequency interference filter
1 power supply
1 circuit pack assembly
1 cable
2 screws
(b)
4 parts:
1 plastic cover (snaps on base)
1 plastic base with molded-in standoffs
1 power supply with internal
radio-frequency interference filter
1 circuit pack assembly
(c)

lated from the relative magnitude of the penalty points.

Combine the penalty points for each motion required for assembly to obtain an overall score for the design, from which the assembly time and cost can be estimated. Three important metrics defined in the design for simplicity method are parts count $N$, assembly time (AT), and assembly efficiency $E$. By objectively describing the proposed product design with these metrics, a base is formed on which to improve the design.

Challenge the need for each part. After describing the assembly motions and calculating the design score, the product team will scrutinize the design to identify ways to eliminate parts and simplify the design. Three questions are used to identify those parts that are theoretically not required.[3]

1. Does the part move relative to its mating part?
2. Must the part be different in material or isolated from its mating part?
3. Must the part be separate because disassembly and reassembly for service would otherwise be impossible?

If the answer to all three questions is "No," then the part can theoretically be eliminated or combined into another part. For example, the standoffs and self-clinching fasteners in Figure 4a do not move relative to the base, are made of the same material, and do not have to be separate for the part to be assembled or serviced. Thus, these parts could be combined with the base as shown in Figure 4b. It is interesting to note that screws, nuts, washers, and similar fasteners are never required parts according to these criteria.

**Figure 4. An example of iterative design in which the number of parts is greatly reduced and the assembly process is increasingly top-down in a "layer-cake" construction. The first design (a) of an electronic package contains 28 parts. In the first redesign (b), the parts count is reduced to 8 by eliminating many of the theoretically unnecessary parts, and assembly motions become simpler. In the second redesign (c) the assembly process has been simplified even further. Two screws have been eliminated, while two parts have been moved into a subassembly; these changes were found to be cost-effective for the overall product. The assembly process is now completely top-down.**

Another important metric in improving a design is the TMNP. After the three questions have been answered for every part in the design, those parts that theoretically cannot be eliminated constitute the metric TMNP. Achieving a product design with a parts count that is identical to the TMNP is extremely difficult and requires good mechanical design skills. Designers have found that calculating the TMNP provides a personal incentive to improve the design. Simple products (less than 20 parts) can often be developed so that they approach their TMNP. More complex products (more than 200 parts) rarely reach production with a parts count less than 150 percent of the TMNP.

Iterate the design. The first design is never the simplest or most cost-effective design. The analysis and score of the original design identify areas for possible improvements. The design team must then redesign and improve the product on the basis of this information and attempt to eliminate the unnecessary parts. Two major goals are to reduce parts count and reduce assembly time. Some of the best simplifying ideas come from group brainstorming.

One way to decrease the assembly time of the product is to design subassemblies. Assembly time in the factory can be decreased by having a vendor ship an assembly of parts, such as a power supply. Of course the vendor charges for the assembly time incurred, but the tradeoff may be cost-effective, especially when the subassembly is produced in a less expensive production environment. The following factors are important in making the decision to purchase a subassembly from a vendor:

- Can the vendor do the subassembly faster, less expensively, or with higher quality, because of its tools, technology, experience, or labor rates?
- Does the subassembly allow the vendor to perform a functional test to verify that it meets the requirements?
- Is the vendor making mating parts?

**Panel 2. Is a Subassembly More Cost-Effective?**

Occasionally, it is difficult to determine whether using a subassembly will be more cost-effective than designing individual parts. An approximate break-even analysis can be done by applying the equation below. A more accurate analysis can be done by taking into account the specific design, manufacturing, and service processes. On a per-unit basis, a subassembly will be cost-effective if

$$\sum_{i=1}^{n} C_i + (\mathrm{AT}_i - \mathrm{AT}_s)L_A + 2(\mathrm{AT}_i - \mathrm{AT}_s)L_S\mathrm{FR} + (n_i - 1)C_c > C_s + C_D$$

where $C_i$ = cost of individual parts (including tooling and shipping)

$\mathrm{AT}_i$ = total assembly time to put parts into product (determined by DFS)

$\mathrm{AT}_s$ = total assembly time to put subassembly into product (determined by DFS)

$L_A$ = labor and load rate at assembly plant (accounts for purchasing, stocking, etc.)

$L_S$ = labor rate for service personnel

FR = frequency of removing parts in the field (includes service and feature add-ons)

$n_i$ = number of individual part types

$C_c$ = documentation and administrative cost of a part (per-product basis)

$C_s$ = cost of subassembly (including tooling and shipping)

$C_D$ = cost of extra effort to develop subassembly (per-product basis)

If the left side of the inequality (the discrete-part extra-cost items) is substantially higher than the right side (the subassembly extra-cost items), a subassembly should be seriously considered. It is assumed, of course, that there are adequate resources to develop a subassembly in an acceptable time interval.



Panel 2 describes the primary cost factors to be considered in subassembly design.

Measure the redesign. After redesign, the metrics are recalculated. The parts count, assembly time, assembly efficiency ratings, and TMNP are calculated for the new design.

Compare and iterate with redesigns. The value of the redesign can best be understood by comparing it with the previous design. Compare the values of parts count, assembly time, and assembly efficiency rating for the original design and the redesign.

Improved metrics for the redesign encourage the design team to pursue further improvements. The TMNP based on the second design identifies the possibilities for further reduction in parts count. With this information, iterate the DFS process until no cost-effective redesigns can be made. For example, Figure 4c shows another iteration of the design from Figure 4a. Notice that, although the second design (Figure 4b) is much better than the first, there was still opportunity for

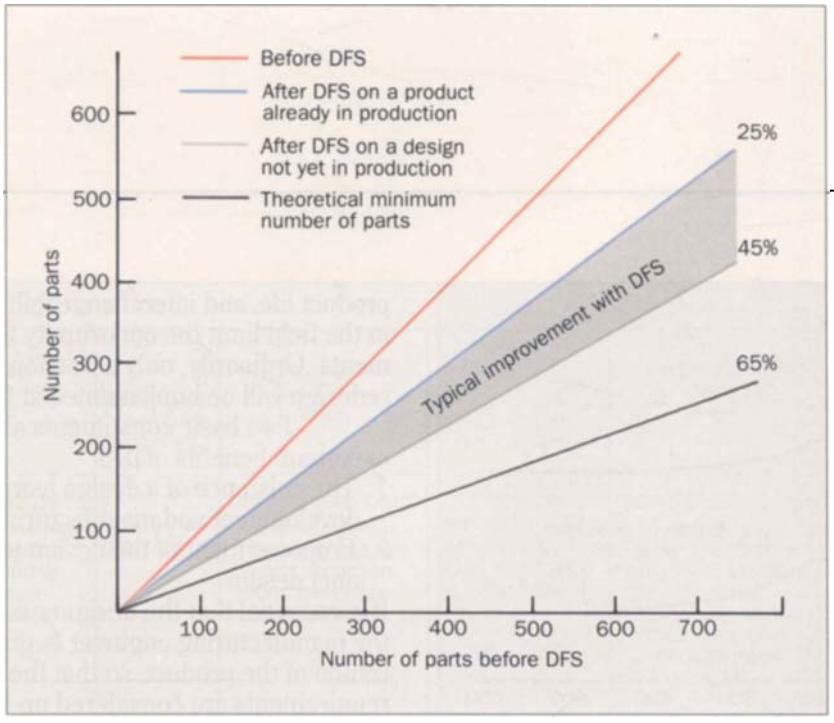



**Figure 5. Parts count before and after application of design for simplicity principles. The typical improvement with DFS is a reduction of from 25 to 45 percent in number of parts. The theoretical minimum number of parts was 65 percent of the pre-DFS parts count.**

improvement in terms of parts count, assembly time and product complexity.

The number of iterations and the number and complexity of subassemblies are determined by the product development budget, projected volume, time-to-market requirements, and the optimum product design zone. The parameters that control this level are complex, and deciding how many iterations are enough requires sound engineering and business knowledge.

#### Power of DFS

The impact of DFS on a design is obvious to the design team, especially when they apply the principles to an existing product. What is missed by not using DFS becomes clear. Product designs can usually be improved by a 25 to 40 percent reduction in parts, as shown by the slopes of the lines in Figure 5. The lines shown in the graph are from data gathered on real products of AT&T and other companies. The original products were designed by experienced engineers. However, the same engineers, after applying DFS, will typically implement a 25 percent reduction in parts compared to a product designed without the benefit of the DFS method or a similar method, such as *product design for assembly*[4] or the *assemblability evaluation method.*[2] Note that DFS performed on a new design will typically yield a decrease of approximately 45 percent in parts versus 25 on a design already in production.

In addition to parts count, assembly time can usually be decreased by 40 percent, as shown in Figure 6. As the graph shows, the fewer the number of parts in the original design, the higher will be the percentage of assembly time that can be reduced in the design. This trend is evident because of the less complicated designs for products with fewer parts.

AT&T is using DFS on an increasing number of new and existing products, ranging from consumer products, such as telephones, to large PBX cabinets. Less costly designs with the same or increased functionality are making customers happy. One example is the changes made to the AT&T 3B2/600 computer, a microcomputer that can handle 64 to 256 users. Although this product was in high-volume manufacture, some DFS changes were implemented, such as the introduction of embedded small computer systems interface (SCSI) peripherals and piece-part changes, that resulted in an annual savings of about $1 million in manufacturing costs.

There are many other proponents of DFS besides AT&T, including General Electric, 3M, Boeing, General Motors, Hewlett-Packard, Pitney Bowes, Unisys, and

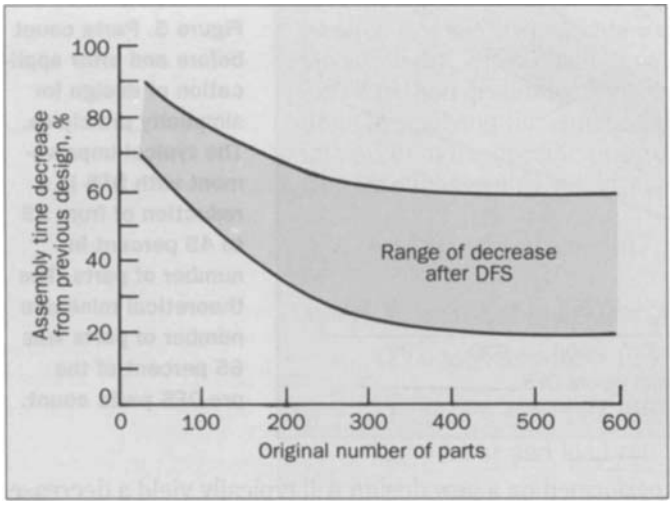



**Figure 6. Design for simplicity greatly decreases assembly time. For larger systems (originally containing about 500 parts), assembly time is usually 20 to 60 percent less than the pre-DFS assembly time, with an average of 40 percent. For simple products (originally containing about 50 parts), the reduction in assembly time is even more dramatic, averaging about 80 percent.**



others. The popularity of the method stems from its proven results. The DFS method brings more to the PRP than just the preaching of design rules. It gives a structured approach to designing, such that the assembly steps are considered, and it gives an excellent process for identifying parts that are not required. It also provides a method to measure the design against established standards.

### DFS in the Product Realization Process

Although DFS can be performed on a product at any time, even in production, the opportunity for redesign to improve the assemblability is drastically reduced when it is used late in the PRP. Once a product is in manufacture, constraints such as new tooling costs, product life, and interchangeability of new parts with old in the field limit the opportunity for product improvements. Ordinarily, only a fraction of the ideas for redesign will be implemented at this stage.

Two basic constituents are necessary to reap the maximum benefits of DFS:

1. The existence of a design team composed primarily of development and manufacturing engineers.
2. Empowerment of the design team to create the product design.

It is essential that the designer consult frequently with the manufacturing engineer beginning with conceptualization of the product, so that the manufacturing process requirements are considered up-front and factored into the design.

In the case of the AT&T 3B computer product line, the design/manufacturing team is physically separated by 700 miles, but by taking advantage of the communication of designers and manufacturing engineers during the DFM process, DFS was implemented as an integral activity. Like the DFM process, DFS is a continual process, and needs regular checkpoints to assess how the design is progressing. Figure 7 shows how DFS relates to the three DFM review meetings held during development of a product: mock-up, prototype, and preproduction.

By the time of the mock-up DFM, a rough idea of the design implementation is available. Not all piece parts are identified. This is the time to assure that all manufacturing requirements are addressed. Although the product design is too sketchy to score with DFS metrics, good DFS design practice should be driving the design of the assembly, including use of top-down assembly, common parts, and subassemblies. Also, the design team should begin reviewing proposals and requirements with their vendors.

At the prototype DFM, the piece parts have been identified, and assembly and process issues can be addressed specifically. The design should be scored with DFS. The brainstorming ideas generated to approach the

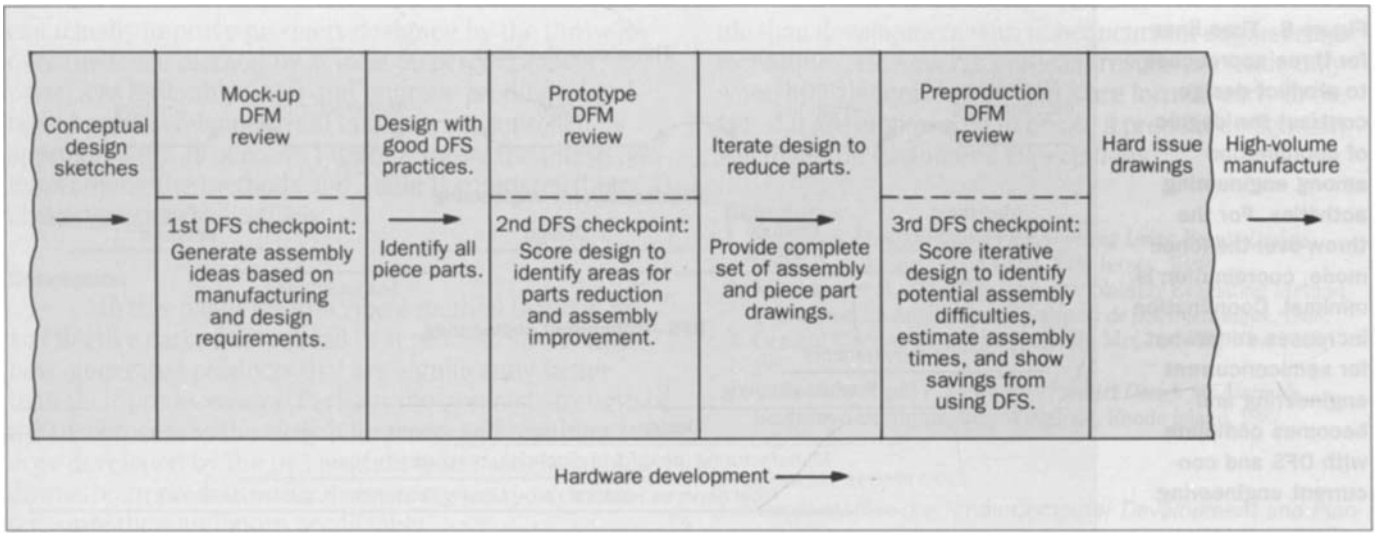



**Figure 7. Checks of DFS progress are made at DFM review meetings held during product development. The DFS process continues between meetings, aided by ideas proposed and accepted at the reviews. Design for simplicity and design for manufacturability are thus continuous, complementary processes that start with conceptual design sketches and culminate in high-volume manufacture.**

minimum number of parts are considered for inclusion in the design. Key piece-part suppliers should be invited to review or participate in this process.

The preproduction DFM is held when there is a complete set of manufacturing documentation. The design is fairly stable at this point and only minor items can be changed. The redesign from the prototype DFM should be scored. The metrics serve these purposes:

1. They highlight any parts that will be difficult to assemble.
2. They give a first-order cost estimate of assembly time.
3. The scores can be compared to the earlier version and justify the importance of iterative designs.

The DFS method excites the design team. However, unless it is part of a development process that requires scoring of the designs and begins at the earliest stage, the method is less effective.

#### Alternative Approaches

At the opposite end of the spectrum from DFS and concurrent engineering models is the "throw it over the fence" approach. In this approach, the designer receives the market/product requirements (in writing) from the product management organization. The designer creates the technical development plan without any discussion with anyone further down the product realization chain. The product is designed to meet the features and requirements specified in the product and development plans, but does not incorporate any input from the manufacturing, service, purchasing, installation, or support organizations. The final design is released—thrown over the fence—on the specified due date, and the development organization is relieved of any further obligation. The organizations receiving the design are left to cope the best way they can under the circumstances. Product change is high and the time to

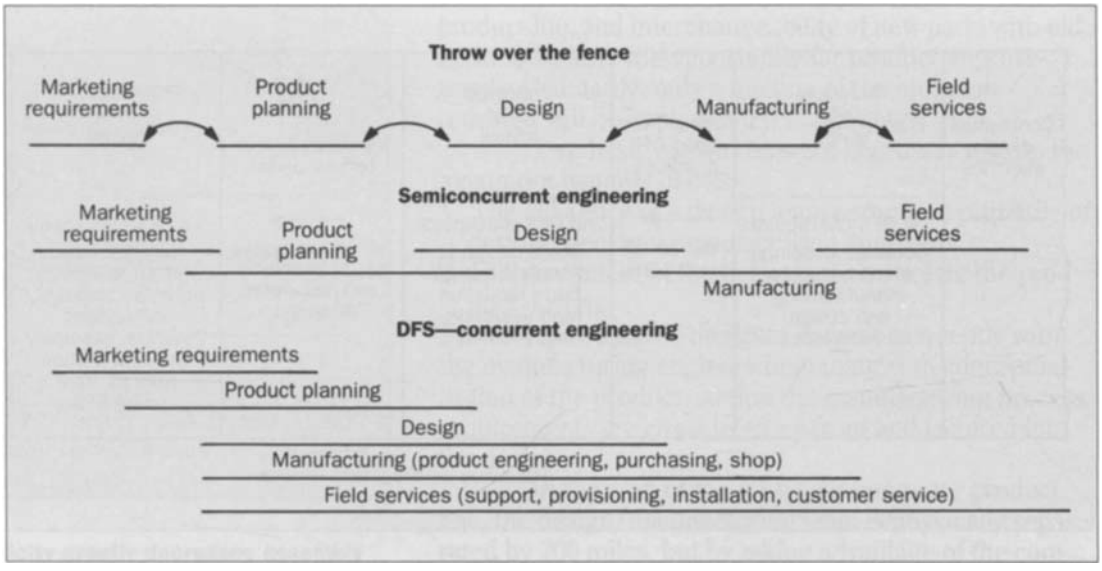



**Figure 8. Time lines for three approaches to product design contrast the degree of coordination among engineering activities. For the throw-over-the-fence mode, coordination is minimal. Coordination increases somewhat for semiconcurrent engineering and becomes complete with DFS and concurrent engineering.**



market is unpredictable, since many problems can occur in this environment. Fortunately, few companies operate this way today.

Today, many companies use a *semiconcurrent engineering* approach to develop their products. They create a contiguous product realization plan and apply sound DFX (design for *X*) principles to each phase. This process allows for considerable overlap of the functional responsibilities, and each customer/supplier in the product realization chain follows accepted process quality management models. Very good products can be developed by this process and, in fact, most modern development organizations follow some form of the model. Product quality is good, product changes are infrequent, and time to market is more predictable.

However, the *total concurrent engineering* approach required in the DFS method—which, of course also employs DFX principles—yields better products. It

**Table II. Qualitative Comparison of Design Methods**

| Method | Development time/effort | Product change activity | Product reliability | Overall product cost | Product quality | Time to market | Customer delight |
|---|---|---|---|---|---|---|---|
| Throw over the fence | Short | High | Low | High | Low | Unpredictable | Low |
| Semiconcurrent engineering | Medium | Medium | Medium | Medium | Medium | Predictable | Medium |
| DFS–concurrent engineering | Medium | Low | High | Low | High | Predictable | High |

can usually improve products designed by the throw-it-over-the-fence method by at least 50 percent (fewer parts, less assembly time) and improve products developed by the semiconcurrent engineering approach by approximately 25 percent. Figure 8 shows the phase relations among the methods and Table II compares their characteristics qualitatively.

## Conclusion

In this paper we describe a method that can be an effective part of the overall DFM process. DFS teams have generated products that are significantly better than their predecessors. Perhaps the greatest strength of the DFS process is the early interaction and resulting synergy developed by the DFS product team, which enables downstream product realization processes to occur faster, smoother, and more predictably.

Customers are delighted with products developed using the DFS method because the product is more reliable, easier to use and service, and has greater value. Product teams are delighted with products developed by the DFS method because all key team members have up-front input into the design process, and the resulting product is the consequence of decisions, judgments, and tradeoffs made by the informed team. The entire cycle of product development is more predictable and less volatile than development with nonconcurrent engineering techniques. However, significant results are made only when knowledgeable DFS teams are formed early in the PRP and are empowered to create a product design that will meet the customer's expectations.

## References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Biographies (continued)

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*(Manuscript received January 12, 1990)*