Design for Assembly – The Key to Design for Manufacture

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The results of the applications of design for assembly techniques to two typical designs are presented. Consideration is given to the total product cost and it is found that major cost reductions can be achieved even when assembly costs are relatively small. It is also found that assembly automation becomes more difficult to justify as a product design is gradually improved.

1. INTRODUCTION

Design for assembly, or DFA for short, is now an accepted technique and used widely throughout many large US industries. Experience now shows that DFA analysis provides much greater benefits than simply a reduction in assembly costs. In fact, it appears that DFA is the key to very significant reductions in overall manufacturing costs. During discussions of DFA with prospective users, the statement is often made that for a particular product, since assembly costs form only 10% or so of the total manufacturing cost, techniques that look at assembly costs only are not likely to be worthwhile. Numerous examples are now available which show that the product simplification brought about by DFA analysis often leads to parts cost reductions that are significantly greater than the reductions in assembly costs. In addition, there are numerous other cost reductions which are difficult to quantify. Examples of these would be the reductions in inventory, reductions in record keeping, improvements in material flow and production flow and many other benefits.

The design for assembly technique involves two important steps: (i) minimisation of the number of separate parts; (ii) improvement in the 'assemblability' of the remaining parts. By far the most important of these steps is the reduction in part count – a procedure which is convenient to carry out during considerations of the assembly of the various parts of a proposed product. This procedure, however, is not solely concerned with assembly costs, but, in fact, has much broader implications for design for manufacture.

The procedure for part count reduction developed by the author[1], involves asking three simple questions with respect to each part as it is added to the assembly. These questions are:

- During the operation of the product, does this part move bodily with respect to all other parts already assembled?
- For fundamental reasons, does the part have to be of a different material from all the other parts already assembled?
- Does the part have to be separate from all other parts already assembled because otherwise assembly or disassembly of other separate parts could not be carried out?

Surprisingly, these three simple questions or criteria, applied to each part in an assembly, can lead to the necessary considerations of part count reduction and significant product

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simplification. The resulting benefits can often overshadow the cost reductions due to assembly only.

The incentive for considering design for manufacture and assembly is the need for productivity improvement and cost reduction. Another way to improve productivity and reduce costs is through automation. Of course, the product must be manufactured in quite large quantities before automation could be considered, but if manufacturing conditions are appropriate, then automation may be an attractive proposition. It is now widely accepted that the first step should be to consider the design of the product and to change the design, if necessary, to improve the feasibility of automation. Unfortunately, there seems to be a dilemma here – examples are available of product simplification being carried out (with a view to more efficient automation) and the resulting product becoming so easy to assemble by hand that assembly automation provides little return on investment. In this paper an attempt is made to quantify some of these factors and to illustrate the overall impact of design for assembly techniques in typical circumstances.

Effect of DFA on Product Cost and Automation Feasibility

Figure 1 shows an assembly of four major components which has been designed using what would be, in many companies, standard design practice. The three small stainless steel sheet metal components have been kept simple in an attempt to reduce manufacturing costs. To the typical designer there are only four components in the assembly. The various inexpensive screws, washers, and nuts which are used to secure the major components are not considered worthy of consideration. Furthermore, the designer would probably indicate on the design drawings that standard fastening methods were to be used and the small parts themselves would not be shown on the drawing. Table 1 presents reasonable estimates of the cost of each component or part in the assembly, and it can be seen that the total cost of all parts is estimated to be 124 cents assuming reasonably large quantities. With these quantities the tooling costs for the sheet metal components are estimated to be \$30k. Using the Boothroyd Dewhurst DFA procedures[2] the manual assembly cost for this product is estimated to be 98 cents which is around 44% of the total product cost of \$2.22 obtained by adding parts cost and assembly cost.

Assuming the manufacturer is interested in reducing manufacturing costs then DFA might be applied. If the product is already manufactured, changing the design of the product simply to reduce assembly costs would almost certainly not be worthwhile because this would involve reinvestment in tooling. If, however, the product is made in sufficiently large quantities so that automation might be feasible, then, of course, DFA analysis should be carried out.

During DFA analysis, application of the criteria for minimum part count will indicate that the three sheet metal components should be manufactured as one more complicated component. If this can be done and if the spindle can be arranged to snap into place, then the total number of separate parts can be reduced from 24 to two as shown in Figure 2. If the design criteria would not allow the snap assembly action, then perhaps the design shown in Figure 3 could be considered. In this case, there are four parts in the assembly. It might be that, for very good reasons the designer cannot consider an integral sheet metal component but is prepared to simplify the fastening method. In this case, perhaps four screws could be inserted into tapped holes in the base as shown in Figure 4. In this latter design there are eight parts. If each of these alternative designs are now analysed for the cost of manual, high-speed automatic and robot assembly, the results shown in Figure 5 are obtained. This figure shows how assembly costs vary with the number of parts in the design. For manual assembly the costs are roughly independent of production volume. For high-speed automatic assembly, large production volumes are required before the technique can possibly compete with manual assembly. In obtaining the results for high-speed automatic assembly, it was assumed that a production volume of 2.4 million per year was required. Robot assembly, on the other hand, will compete with manual assembly when the production volumes are in the mid-range of a few hundred thousand per year. For the results shown in Figure 5, an annual

Table 1. Summary of costs for design shown in Figure 1.

Item	*Material cost (cents)*	*Manufacturing cost (cents)*	*Total part cost*
Base	13.6	11.9	25.5
Bracket 1	9.3	9.5	18.9
Bracket 2	9.3	9.5	18.8
Spindle	10.7	30.6	41.3
Totals	42.9	61.5	104.4

Total manual assembly cost = 98 cents
Estimated cost of 20 fasteners = 19.6 cents
Total product cost = 222 cents

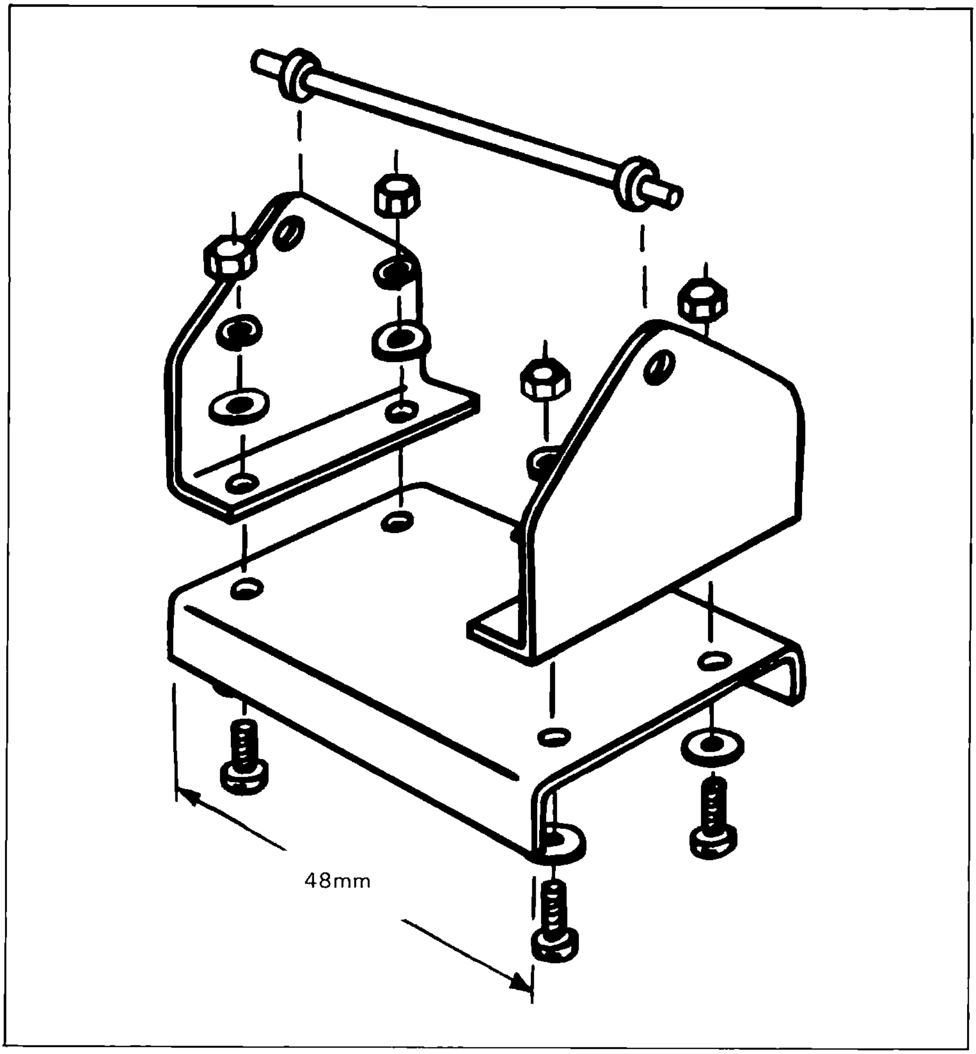

Figure 1. Assembly consisting of four major components and 20 fasteners.

production volume of 200,000 per year was assumed for robot assembly. It can therefore be argued that the figures for each manufacturing method are the most attractive possible. These graphs show clearly that automation becomes less attractive as the product design is improved. For the original design manufactured in large volumes, high-speed assembly automation would give an 86% reduction in assembly costs and for medium production volumes, robot assembly would give a 61% reduction. However, with the most efficient design consisting of only two parts, DFA gives a 92% reduction in manual assembly costs and for this design the further benefits obtained through automation are negligible.

In this analysis only assembly costs have been considered and, as stated earlier, parts costs should also be looked at.

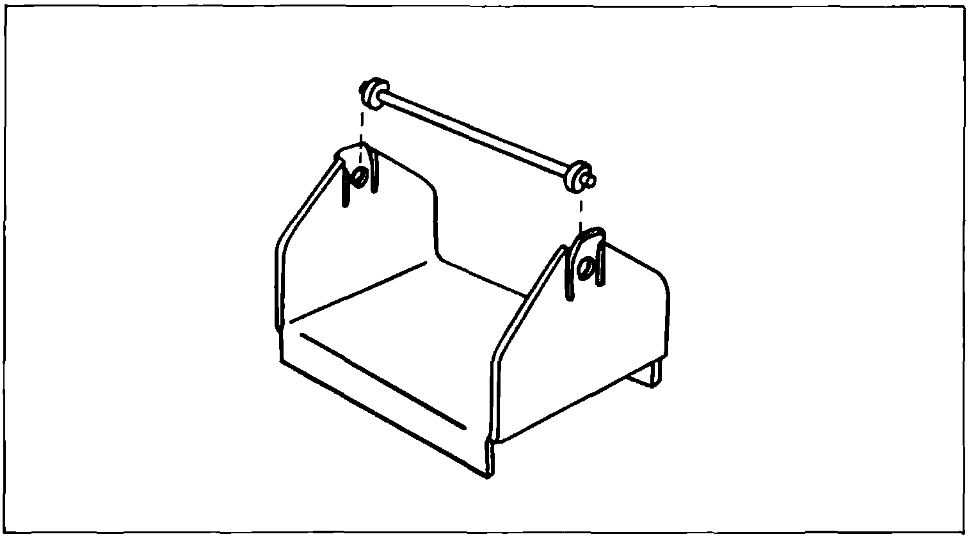

Figure 2. 'Ideal' redesign where two parts snap together.

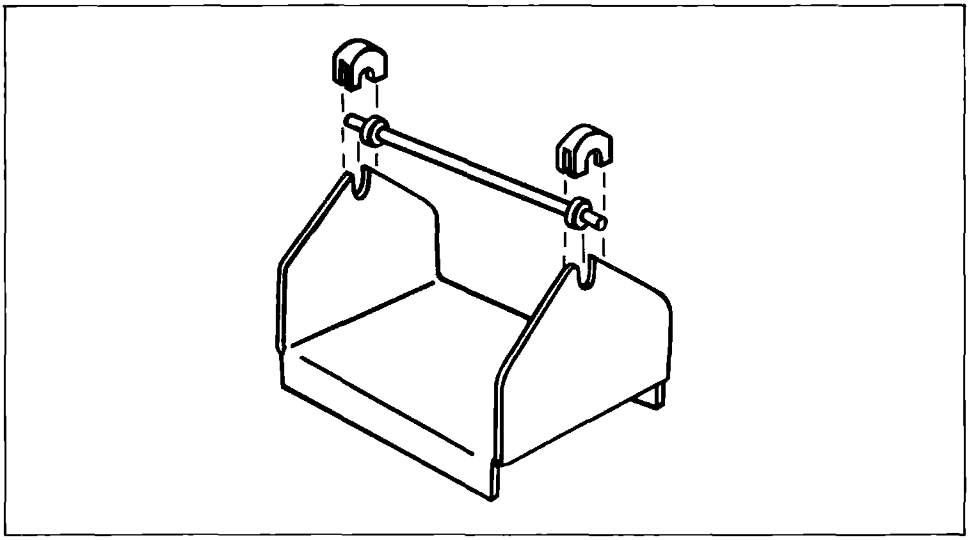

Figure 3. Redesign where spindle is held in place by plastic snap retainers.

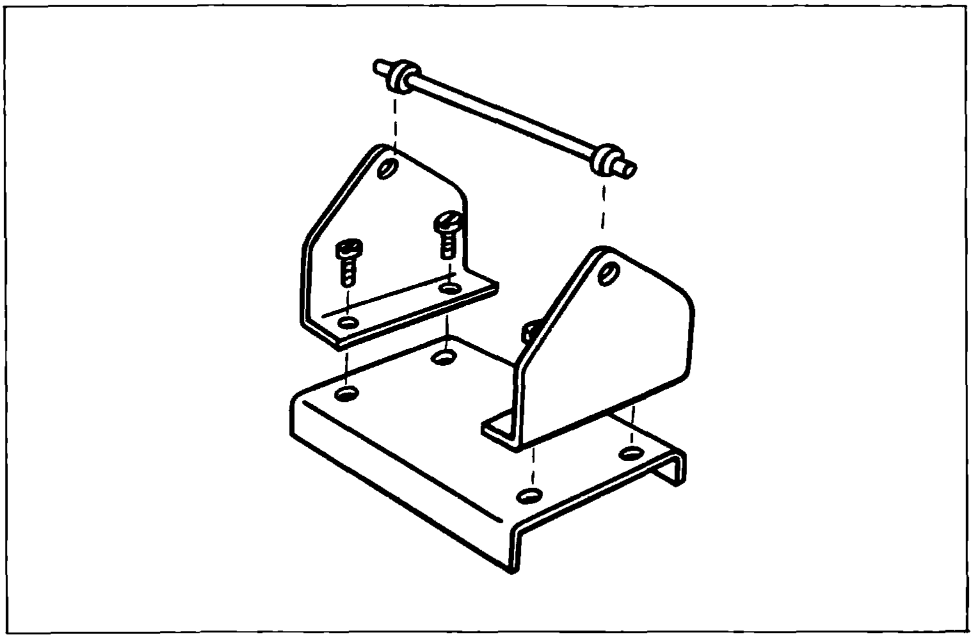

Figure 4. Redesign where sheet metal components are separate but where number of fasteners is reduced.

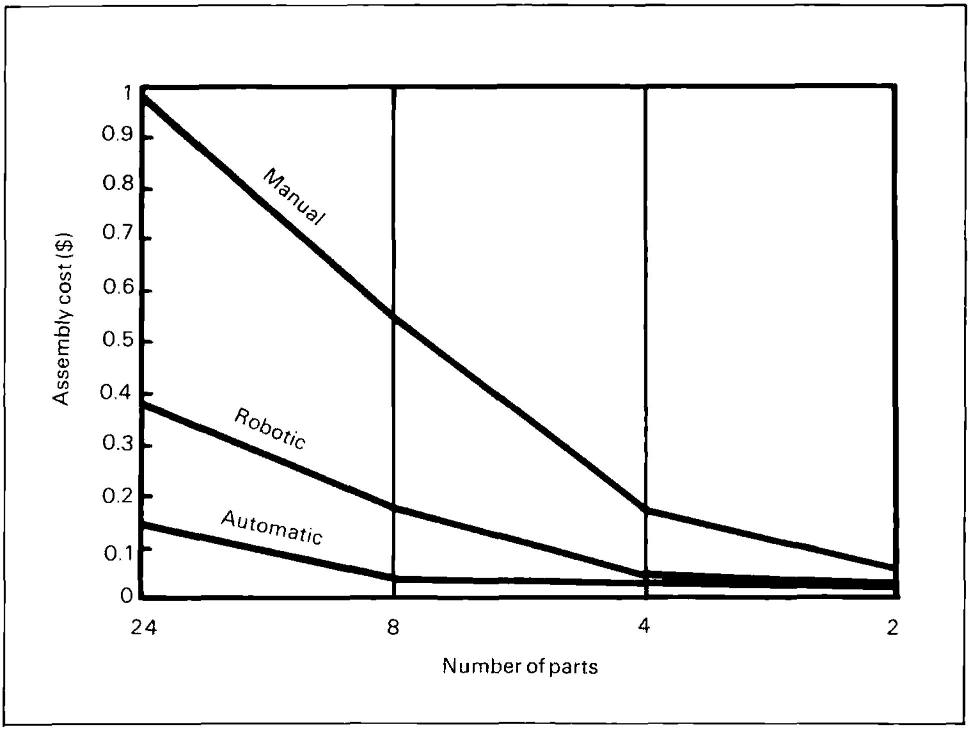

Figure 5. Effects of product design on assembly cost.

Effect of DFA on Parts Cost

For the purposes of estimating parts cost, techniques being developed in the Design for Manufacture Research Program at the University of Rhode Island were employed. It was assumed that each design would be produced in batches of 10,000 and at the rate of 200,000 per year for three years with two shifts working. It was also assumed that the parts were all of 316 stainless steel costing $2.50 per pound. The sheet metal parts were to be produced on a medium-sized punch press from 18 gauge (0.05in thick) sheet. The spindle, turned from bar stock, was the same for each design and was estimated to cost 41.3 cents of which 10.7 cents was material cost. The various small fasteners (nuts, washers, etc.) were assumed to cost 1 cent each on average. A final summary of costs for each design is presented in both tabular and graphical form in Figure 6.

In these results the tooling costs are included in the manufacturing costs and, because of the relatively large volumes, form only a small proportion of the total. The bar charts clearly show that for the most simplified design the assembly costs form a small proportion of the total costs and as a result the possible cost reduction through automation is very small – about 4 cents per assembly. However, automatic assembly of the original design yields a possible saving of 60 cents per assembly which is a significant proportion of the total manually assembled product cost of $2.22.

The cost of the small fasteners is included in material costs and the savings in material costs in designs two, three and four can almost be entirely attributed to the elimination of these fasteners. However, in design two these savings are outweighed by an increase in the manufacturing costs. This is due to the expensive drilling and tapping operations needed for

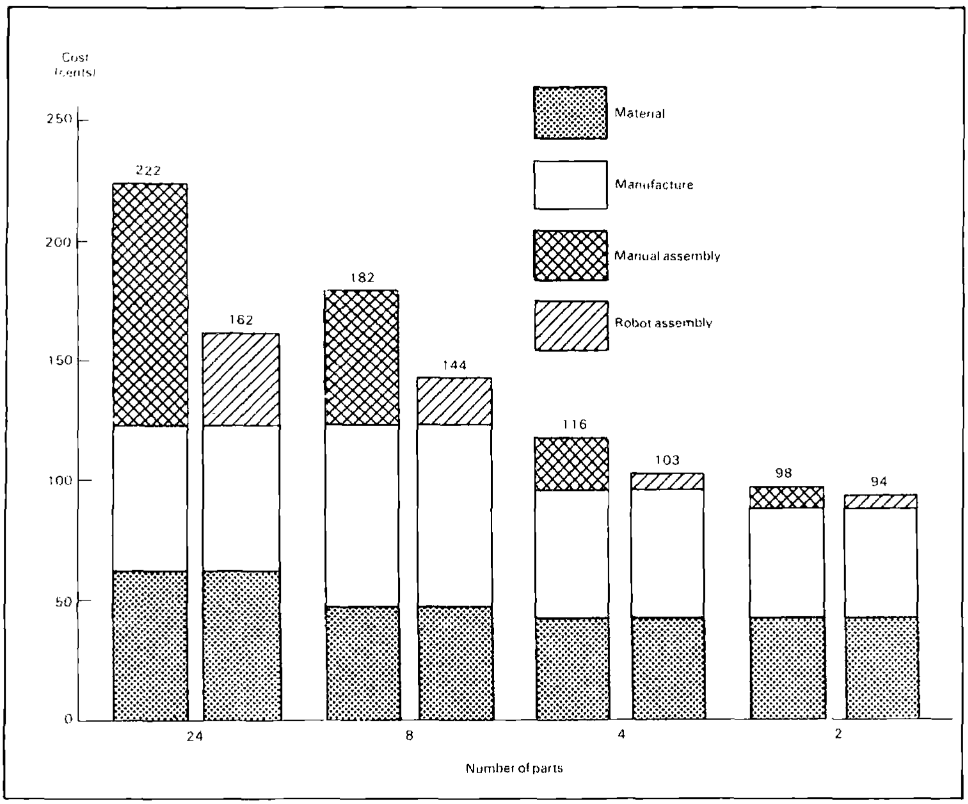

Figure 6. Effects of product design on assembly and parts cost.

the base. In spite of this, however, the total costs are reduced significantly because of the reduction in assembly costs.

In designs three and four reductions in both material and manufacturing costs accompany the significant reductions in assembly costs. For the ideal design for manufacture the total cost is around $1.00 of which 41.3 cents is the cost of the spindle whose design was not changed.

The example of simple sheet metal parts fastened together as in design one is a design solution frequently found in practice. Clearly it represents a situation where considerable savings in assembly costs are possible through redesign and where somewhat smaller savings in material and manufacturing costs can be made.

Another common design solution is represented by the somewhat larger assembly shown in Figure 7. In this case several parts machined from standard work material shapes (bar, plate, angle, etc.) are bolted or screwed together. Table 2 presents a summary of the costs of the individual items for this design, again obtained using techniques being developed at the University of Rhode Island. It can be seen that this product represents an example where assembly costs, although approximately three times as great as in the sheet metal assembly described earlier, are small compared with the cost of the parts. This would be a situation where DFA analysis might not be considered worthwhile. However, such an analysis would indicate that, because none of the major parts move relative to one another and can be of the same material, the designer might consider a casting machined on its operating surfaces, thereby eliminating assembly costs completely. It is estimated that such a casting of 316 stainless steel using the shell moulding process and two cores would cost approximately $2.75 per lb. giving a cost of $45. Tooling costs would be around $3,000 and assuming a small batch size of 1,000 would give a total cost of $48. Machining costs for the casting were estimated to be $3.87.

Figure 8 presents a comparison of the costs of the two designs where it can be seen that material costs have been reduced by 42% and that machining and assembly costs have been almost eliminated. This results in a total product cost reduction of 60%; a saving of over $76.

Table 2. Summary of costs of cylinder-base assembly and one-piece casting

(a) Cylinder-base assembly

Item	*Material*	*Material cost ($)*	*Machining cost ($)*	*Total part cost*
Cylinder	316 s.s.	53.25	20.41	73.66
Base	316 s.s.	26.83	12.68	39.51
Bracket	Aluminium	0.72	2.68	3.40
Post	316 s.s.	1.55	4.23	5.78
Arm	316 s.s.	0.67	1.97	2.64
	Totals	83.02	41.97	124.99

Total assembly time = 357 s
Total assembly cost = $2.98
Estimated cost of 36 fasteners = $0.36
Total product cost = $128.33

(b) One-piece casting

Cost of casting = $48.00
Machining cost = $3.87
Total product cost = $51.87

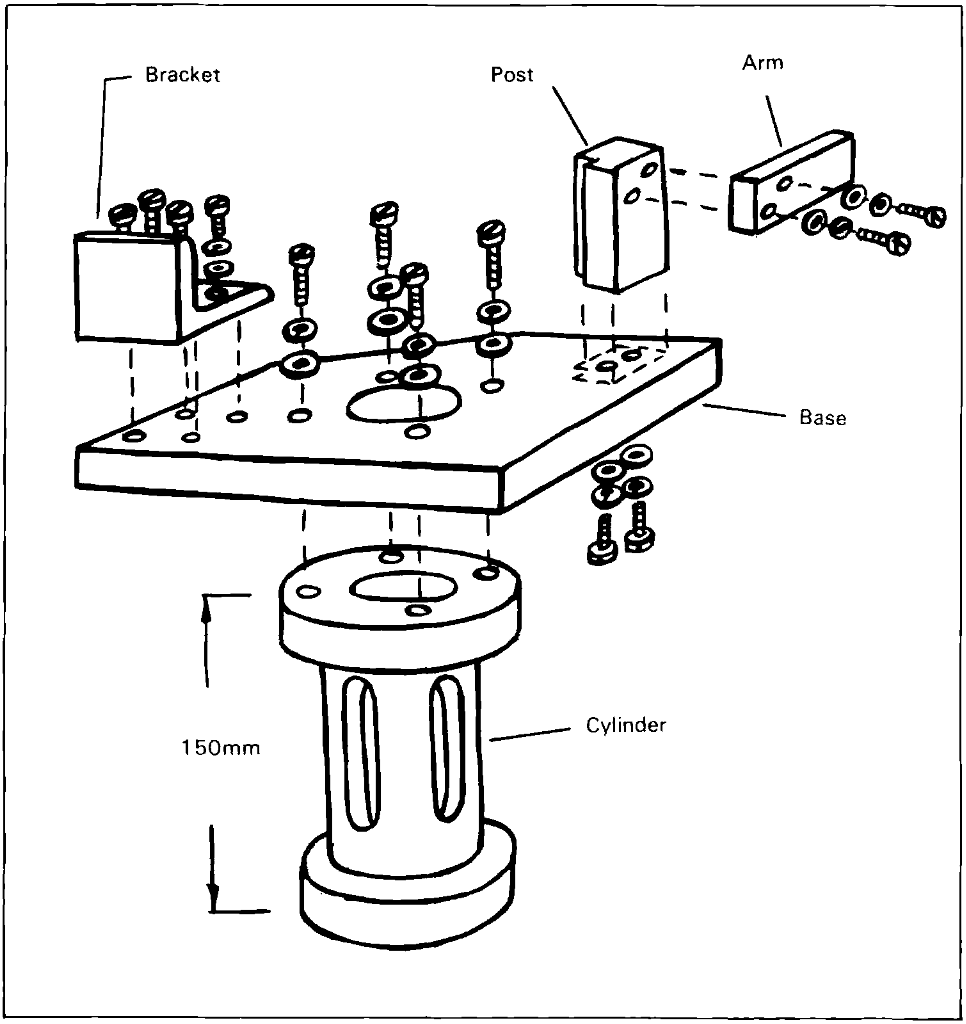

Figure 7. Cylinder-base assembly.

Discussion

The two examples considered here both represent design solutions encountered in practice. The first example was a small sheet metal assembly manufactured in high volumes where assembly costs formed a large proportion of the total product cost. Design for assembly analysis showed how large savings in costs can be made as the design is improved. The second example was a larger assembly of solid machined parts manufactured in small quantities. Because assembly costs seem negligible compared with the cost of the various parts, DFA might not be considered worthwhile. However, even in this case, significant savings can be made through product simplifications as a result of using DFA criteria.

Studies such as these are conducted as part of a research program in design for manufacture at the University of Rhode Island. The main thrust of this program is the development of cost-estimating techniques suitable for product designers. These techniques were used in the estimations of manufacturing costs described in this paper and their development will be described elsewhere. However, these examples serve to illustrate that DFA analysis is the key

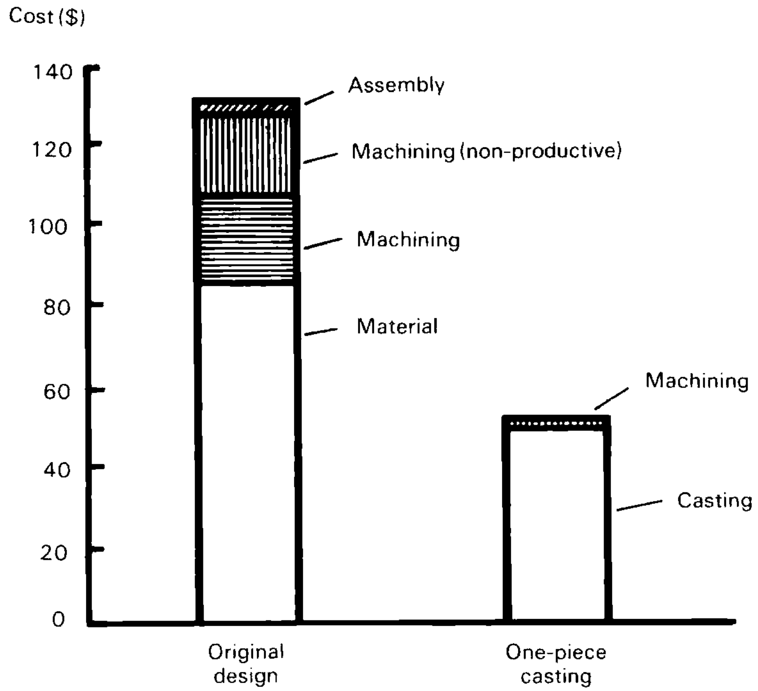

Figure 8. Graphical comparison of costs when cylinder-base assembly is replaced by one-piece casting.

to design for manufacture and should always be applied even when assembly costs are relatively small. These examples also illustrate the need for simple parts cost estimating methods that can be used at the early design stages where trade-offs between various manufacturing methods are being considered.

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