Designing Differently:

There and Back Again[1]

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Abstract

Throughout record time there have been brilliant product design / engineers that have created amazing products. Why is it that more products created do not have these same characteristics? Why is it that more products aren't created that are called classics? One possible explanation is there just aren"t enough brilliant engineers / designer around. So what do mere mortals do ? I think the application of a set of specific design methodologies and the philosophy of Design for Manufacture and Assembly can repeatedly create what are called "Classic Products".

Origins of DFMA

In the 1970's manufacturers discovered the need for peripheral equipment feeders and grippers to present parts so that a robot could place them appropriately in the product assembly. Boothroyd and Dewhurst did pioneering work in assembly automation in product design which included the analysis of parts for automated feeding. (Boothroyd, 1991) As the robotic revolution faded in the United States, design for manufacturing and assembly (DFMA) analysis shifted to the analysis of an entire

[1] In a 1955 letter to W. H. Auden, Tolkien recollects that he began work on *The Hobbit* one day early in the 1930s, when he was marking School Certificate papers. He found a blank page. Suddenly inspired, he wrote the words, "In a hole in the ground there lived a hobbit." By late 1932 he had finished the story. The sub title There and Back Again was to let you know that the events had truly taken place and the author had lived to report on them………………..

product and its constituent parts and subassemblies. parts/subassemblies.[2] Below is a time line of the development of the DFMA software that you Know today. I would suggest that between 1983 and 1988 is where philosophy of Design for Manufacturing and Assembly begins to take shape into the tool that you use today. Funding from NSF (9 years) & Xerox, GE, DEC, AMP Inc., IBM, Gillette, Westinghouse and in 1988 the forming of the Committee for the Advancement of Competitive Manufacturing (CACM) formed. Members included GM, Ford, Loctite, DEC, Navistar, Allied Signal, who were instrumental in shaping the tool into what it is today. Funding for various research topics came from CACM members based on what they wanted to have tools to help do design. Not everything from that period successfully transitioned to current day. A lot of amazing work was done in the environmental area that was way ahead of its time did not get traction.

- 1977 – 1980 Boothroyd starts DFA research, first NSF funding, Dewhurst joins UMass. Faculty

- 1980 -1983 Boothroyd and Dewhurst begin partnership, Development of DFA software for Apple II, conversion of software for IBM PC, DFA handbook published

- 1983 – 1986 DFA PCB research begins, B&D move to Uni. Of R.I. ,
  W.A. Knight moves to URI, release of robotic assembly software, first DFMA conference held.

- 1986- 1989 Work begins on DFM, publication of DFA handbook, machine parts and injection molding software release.

- Funding was provided by NSF (9 years) & Xerox, GE, DEC, AMP Inc., IBM, Gillette, Westinghouse. In 1988 Committee for the Advancement of Competitive Manufacturing formed, Members included GM, Ford, Loctite, DEC, Navistar, Allied Signal

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[2] Meeker, David and Nicholas Dewhurst. “DFMA and its Role in Cost Management” *The 20 th Annual International Conference on DFMA* Warwick, RI June (2005)

- 1988 Committee for the Advancement of Competitive Manufacturing formed, Members included GM, Ford, Loctite, DEC, Navistar, Allied Signal

- 1989- 1991 DFA 5.0 released with PCB analysis, Sheet metal

  DFM released, DFA 5.1 released supporting Macintosh and VMS, Die casting and Powder metal DFM software released.

- 1991 – 1994 Newer versions of DFA, Large parts DFA, and

  Design for the Environment, and additional DFM modules released

- 1991 National Medal of Technology Recipients

  "For their concept, development and commercialization of DFMA, which has dramatically reduced costs, improved product quality and enhanced the competitiveness of major U.S. manufacturers."

30 Years of Innovation Origins, History and Evolution (cont.)

- 1994 -1997 Updated versions of DFA and DFM, and Design for Service software release.

- 1997 -2015 versions 7, 8, 9, 10 of DFA released as well DFM concurrent costing 2.0, 2.3, Major software rewrites to keep up with ever changing Microsoft operating systems

Because the DFMA tool is modular and looks at basic building blocks of parts and subassemblies, it can be applied to a wide range of tasks throughout the product development lifecycle. The DFMA process can add value in a number of ways including early product costing, competitive product benchmarking, the creation of time standards, material selection, assembly instructions, quality improvement and vendor quote verification, but part count reduction produces the greatest cost reduction.[3] [4]

Other Design Methodologies

There are lots of other design methodologies out in the real world that attempt to help designer explore the complicated space of mechanical, electrical, materials, and software into making a truly classic product. G. Pahl and W. Beitz published Systematic Engineering Design which looks to explore all facets of a design from basic engineering principles in an attempt to optimize the final outcome. Nam Suh Axiomatic Design which aims to represent the product design is a high level system architecture – domain and design axioms which allow for the creation of corollaries and theorems which than can be used as design rules to optimize the product design.

In the end, many of these designs have been optimized but seem to fall short of classic robust products. A great recent example of this can be found in the kick starter product Juicero so over engineered it is scary but when you look at sub-assemblies they have all been optimized.

Which leads us to the most powerful design impact philosophy of Design for Manufacturing and Assembly which enables mere mortal engineers and designer to create great products.

It is the notion that every product can be built with a Theoretical Minimum part (TMPC) and that this number can be reliably calculated. I would argue that is striving to reach that (TMPC) number drives innovation and creativity that helps create classic products

Why is part count reduction so important?

Product design, specifically its resulting part count, generally determines a product's cost and influences its quality. Consider the life cycle of a part in the manufacturing process. The design engineer's concept deems a part as critical. An engineer creates a CAD model of the part, assigns a part number and places it in the 'system' by adding it to the bill of materials (BOM). The engineer's drawing specifies the part's dimensions with

[3] Meeker, David. "DFMA a multifunctional Analysis Tool" *The 22nd International Conference on DFMA* Warwick, RI June (2007)

[4] Special thanks to Dr. Luanne Isherwood for comments and suggestions.

appropriate tolerances needed for the product to function as desired. These are checked (hopefully) and signed off on by a senior team member. The purchasing department then sends the part's drawing to suppliers for price quotes in order to select a supplier. Then the production of the part begins. The supplier creates the part and deals with manufacturing issues. The company receives the part, also inspects it and then lists the part as inventory, placing it on a shelf in the warehouse. The assembly line retrieves the part, moves it to an assembly station and then finally an assembly worker installs it into the product. This process happens hundreds or even thousands of times, depending on the company and the products that it produces.

Just take a few minutes to think about the time, and ultimately the cost, that one part in a product generates. Examined in such detail, one wonders why the obvious question, "Is the part actually required?" is not asked first. This life cycle of one part generates considerable cost and it is the reason that applying DFMA to part count reduction is vital to the success of a product. Ultimately, the design of a product controls the majority of a product's cost and once implemented, cost savings are difficult to achieve. Given what is at stake, it is hard to understand why techniques available to help part count reduction are not a normal part of how product design is done. Putting a number on the true cost of a part requires looking beyond material and labor costs; it requires adding costs from a number of disparate cost centers. Companies need to document what it truly costs to own their part numbers.

The Parts Standardization and Reduce Program Costs through Parts Management is a consulting study by Convergence Data Services Inc. that documents the cost of adding a new part into the inventory results from six program areas: engineering and design, testing, manufacturing, purchasing, inventory, and logistics support. Table 1 summarizes these average costs by program activity. While it is possible that in some cases the added costs of adopting a unique part design could be offset by lower manufacturing or purchasing costs, such choices should be justified and carefully documented. [5]

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[5] This document can be found at http://www.convergencedata.net/Docs/PartsMgt.pdf.

Table 1. Average Costs for Adding a Part into a System

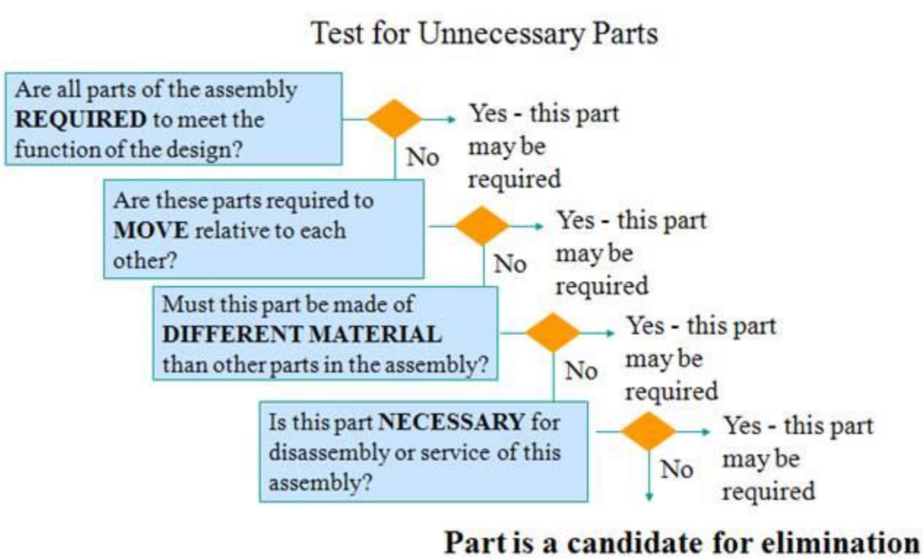
Activity	Cost
Engineering and design	$12,600
Testing[a]	1,000
Manufacturing	2,400
Purchasing	5,200
Inventory	1,200
Logistics support	5,100
Total	$27,500

[a]The testing cost was reduced significantly because not every part added to inventory requires testing. However, every part needs to be evaluated, either by similarity, bench test, or analysis.

So how does one determine Theoretical Minimum Part Count (TMPC)?

Boothroyd and Dewhurst (B&D) developed the concept of theoretical minimum part count (TMPC) to serve as a goal for a product designer to be able to quickly determine the number of parts required to accomplish a desired function within a product.

So how do you determine a TMPC for product/assembly you are working on? Answering a simple set of questions can help to determine whether a part / subassembly would be a good candidate for elimination from a given design.



If the answer to all of these questions is "NO" then likely the part should be eliminated. As the product designer works through the initial concept, he should ask these questions with each part. By including and eliminating parts, the designer can achieve a design with this TMPC.

Classic DFMA case study Epson MX80 vs. IBM Proprinter

Albeit, an older example, comparing the Epson MX80 design with the IBM Proprinter design clearly illustrates the use of TMPC to simplify a product.

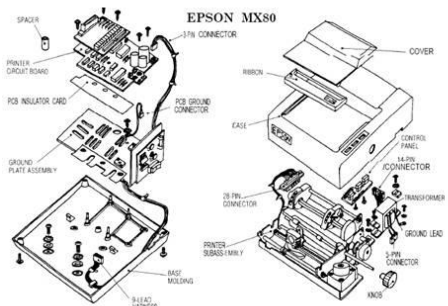


FIG. 1

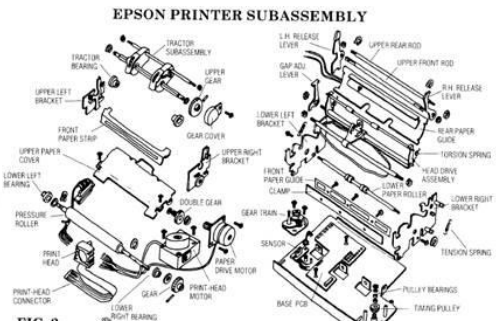


FIG. 3

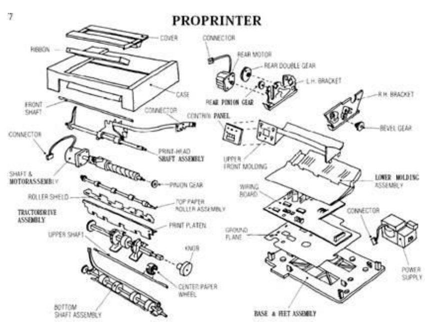


FIG. 5

Epson MX 80		IBM PRO Printer	
Total Assembly time (sec.)	1866	Total Assembly Time (sec.)	170
Total Number of operations	185	Total number of operations	32
Total parts/subs.	152	Total parts/subs.	32
Theoretical part count	41	Theoretical part count	29

When looking at these two different designs which one would you like to be responsible for the:

- Quality of final product
- Supply chain for
- Manufacturing line set up
- Total product cost
- Keeping the product design on schedule through all those design verification builds
- Warranty cost
- And so on …………………………………………………..

It is clear when you look at the total number of parts and complexity of the parts as well as subassemblies that the Proprinter is the superior design. The simplicity of the Proprinter goes far beyond just the part count, it was completely assembled by a robotic assembly line. The design also follows many of the DFMA design rules of Z- axis assembly, self-locating features, use of snap fits, and some very clever solutions for attaching rollers to a rod.

In addition to answering simple TMPC questions, there are a number of ways that you can help identify parts that might be eliminated from a design. For example, using design guidelines can help you reach the TPMC goal. The design engineer might also consider questions about theoretical part count that are another layer of thought deeper, and look at form and function, touching surfaces, same material, and other subtleties whose aim is to tease out parts that are candidates for elimination

Subtleties of Minimum Part Criteria:

- If a material already exists in structure chart, can a single part be used in place of two separate parts of the same material?
- Even if a part is "theoretically necessary", i.e. a circuit board, can the number of these parts be reduced in the design?
- Focus on functional requirements of the part/assembly (verb noun pair):
  - Candidates for Elimination
    - Secure parts
    - Transmit signal/load
  - Theoretically necessary
    - Relative Movement
      - Compress gas
      - Measure position
    - Different Material
      - Seal interface/prevent leaks
      - Insulate/block heat
      - Conduct heat
      - Conduct electricity

So Why Do So Many Product Designs Fail to Have the Theoretical Minimum Part Count?

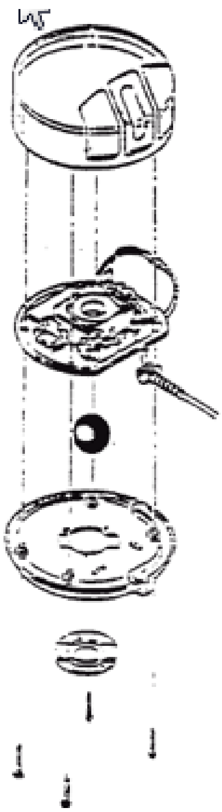
The **first** and simplest reason is design engineers ignore the technique during the product development cycle. Surprisingly, the methods described above are not well known. Once explained, the concepts are easily digested but this information needs to be disseminated among the manufacturing community.

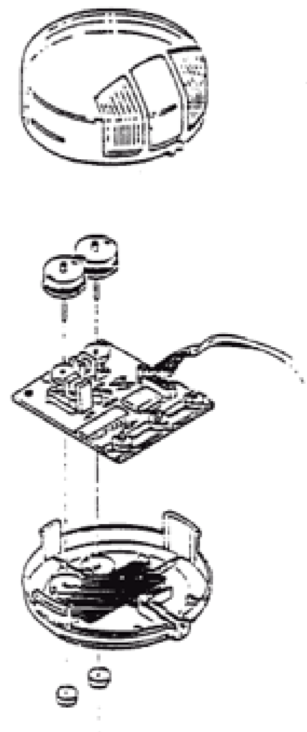
A **second** reason is that even when companies are aware of the aforementioned techniques, they have not embedded their use in the organization. Gate reviews, design reviews, and design verification builds do not emphasize this technique as a critical part of the process. A number of organizations actually collect the information and still fail to use it. This is a tragedy. In the head long rush to meet the launch date for a new product, reaching the goal of TMPC falls to the side.

Finally, cost reduction in many companies is still considered only as quick fixes after the fact. The design team only realizes that the cost of the product is a problem near the end of the development cycle. To address this, they attempt quick fixes like, negotiating with vendors, substituting less costly parts, possibly removing a feature from a product, and shipping the product overseas for manufacture. These quick strategies do reduce cost but are not nearly the cost reduction that a design created with a TMPC would yield. In fact, best practice would be to apply these quick fixes once you have the TMPC design.

Case Study Digital Equipment Corporate (DEC) Mouse

Another classic example of a DFMA redesign that focused on using Theoretical Minimum Part Count as one of the critical design evaluation tools in producing the new design is the DEC mouse.





	Old	New
Part count	61	44
mechanical	31	16
electrical	30	28
Assm. Time	17 min.	6
Assm. Oprs.	83	56
Adjustments	11	0
Fasteners (3 types)	10	0
Material Cost Reduction		>40%

In this design, using the TMPC criteria as part of its design process enabled the design team to reduce the total part count by 32%. The design tem scrutinized each part and subassembly to be sure that it complied with DFM rules. This reduced mechanical parts by 48%, electrical parts by 6%, assembly time by 64%, and assembly operations by 32%. Fasteners and adjustments were eliminated completely as well. The design also reduced material costs by 40% over its predecessor.

The team also introduced a new encoder technology, the slant foot encoder technology that eliminated all the adjustments the old trackball cage previously required. With this design, the mouse would not fail even if the user ran the mouse through catsup. This design also enabled the pixel resolution to be increased by changing the radius of the feet. Two small magnets under the plastic encoder caps also enabled the mouse to track on vertical surfaces or even upside down. When rigorously applied TMPC is a powerful tool for attacking and lowering total product cost.

At the end of the day it is about total product cost – great products that have no margin will never keep you in business unless you are selling supplies ie ink cartridges. There are methods and tools for understanding and influencing total product cost. Not just those costs associated with materials, processes and labor. But the downstream tally and savings that stretch from workstation to shipping, to warranty and service.

Knowledgeable teams of designers, manufacturing engineers, purchasing staff and managers can achieve total product cost savings by focusing first on the design elements that continue to impact everything that follows.

TMPC is the tool coupled with Design for Manufacturing that is able to reduce product cost across the entire product spectrum and produce timeless classic designed products

Perfection is reached not when there is no more to add but when there is no more to take away."

Antoine de St. Exupery