30 Years of Innovation:

The Evolution and Application of DFMA

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Abstract

Paper will look at the evolution of DFMA methodology and tool, and the various ways DFMA tool has been applied to help refine product design.

Setting The Stage

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. With funding from NSF 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, analysis in the area of design for manufacturing and assembly (DFMA) shifted focus to the analysis of whole products and their constituent parts and subassemblies. If 70 – 80% of a product's final cost derives from materials, it stands to reason the fastest way to reduce cost would be to eliminate parts/subassemblies.[1] Boothroyd and Dewhurst turned their research focus from orientation of parts in feeder to analysis of actual parts in subassemblies / products showing that the same/ similar rules could be applied to produce more elegant designs. At a higher level of product analysis Boothroyd and Dewhurst developed the concept of theoretical minimum part count[2] which serves as a goal for the product designer to achieve, yielding a design with the fewest part/subassemblies possible.

To determine if a part was a candidate for elimination a set of simple questions were developed.

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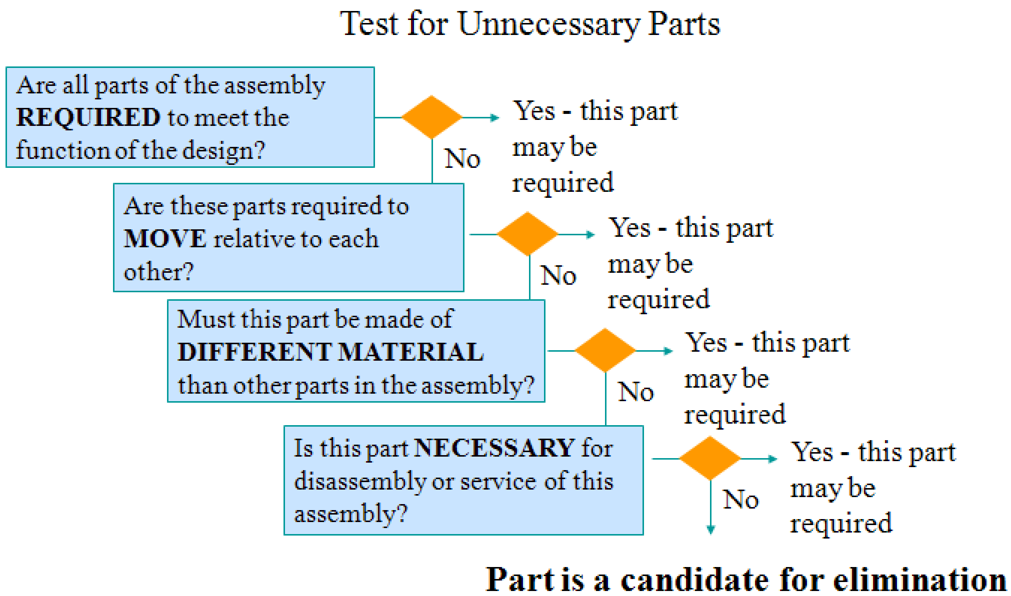
[1] Meeker, David and Nicholas Dewhurst. "DFMA and its Role in Cost Management" The 20 th Annual International Conference on DFMA Warwick, RI June (2005)

[2] Manufacture and Assembly 2nd edition, G. Boothroyd, P.Dewhurst, W. Knight, Marcel Decker NY, NY, 2009. Pg's 12 & 94



If the answer to all of these questions is "NO" then this part is a good candidate for elimination. The exercise of how to design the product and hit the theoretical minimum part count was left to the imagination and creativity of the design team.

Flavor of the Month

Over the last 30 years, you have heard the slogans of the flavor of the month "Automate, Integrate or Evaporate" ---- Six Sigma is on by my count its third or fourth industry revival since Robert Galvin along with John Mitchell and Motorola engineer Bill Smith, in implementing the six sigma quality system_ at Motorola. In its current incarnation it has been combined with Toyota's Lean philosophy / strategy to become Lean Six Sigma. Throughout this time DFMA has been a mainstay of design methodologies that offered proven results throughout the product development cycle. From the preverbal sketch on a napkin to a products end of life. The DFMA tool and its methodology / philosophy is one that has allowed it to adapt too many uses. In 1980's when the invasion of low cost high quality goods began appearing from Japan and Xerox institutionalized benchmarking.

Benchmarking - The continuous process of measuring products, services and practices against the best competitors or those recognized as industry leaders. [3]

In 1979 Xerox wanted to understand, "how in the world could the Japanese manufacture [a copier] in Japan, ship it over to the United States, land it, sell it to a distributor who sells it over to the dealer who marks up the cost to the final customer, and the price the final customer pays is [still] about what it would cost us to build the machine in the first place".[4] In the course of trying to understand the competition, Robert Camp of Xerox defined the benchmarking process. This required Xerox to look to the hardware as a source for understanding and comparison, a major part of the benchmarking process.

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[3] Camp,RC, 1989. Benchmarking: The Search for Industries Best Practices that Lead to Superior Performance, Quality Press
4 Jacobson, G. and J Hillkirk, Xerox: The American Samurai, Collier Books, 1986 pp. 233-234

Simply put **Product Benchmarking** is the act of measuring a product against some standard. In common industry parlance this is measuring your product against your closest competitor. Using the DFMA process and tool during competitive product benchmarking enabled you to quantify lots of information about competitors' products, and gave you an apples to apples comparison to your own design.

Many companies started using DFMA in assembly analysis but quickly realized it could be applied to a whole host of other related activities that occur during the product development cycle.

These area of use include but are not limited to;

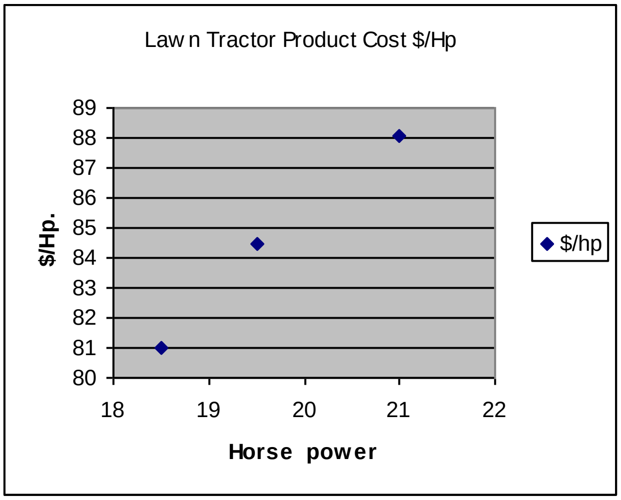
- Competitive product benchmarking (mentioned above)
- Concept Selection
- Early product costing
- Early product costing at sub assembly level (metrics)
- Creation of time standards
- Creation of assembly instructions
- Design simplification
- Cost reduction activities
- Outsourcing to far east
- Vendor quotation verification
- Helps generate IP

Early Product Costing

It is possible to do early product costing with DFMA. Taking past product cost data and looking at attributes of your particular product it should be possible to create a metric such as dollars per pound, dollars per cubic inch, dollars per axle, or dollars per horse power.

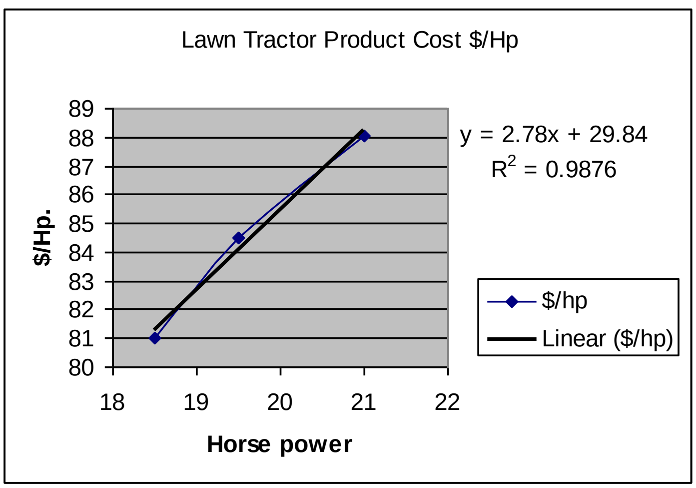
In an over simplified generic example; lawn tractors.

The entry level 18.5 HP 42 inch cut   cost $1499.00, the 19.5 Hp. 42 inch cost $1649.00, and the 21 Hp. 42 inch cut $1999.00. Next choice an attribute for your product such as weigh or maybe horsepower and plot the data to see what the relationship looks like



Next curve fit the data to come up with an equation that best fits the data.

What has resulted is a linear fit that relates horse power to product cost with a high degree of accuracy.



Early Product Costing at the Subassembly Level

The next level of product costing is at the subassembly level. This helps to take into account changes that new products typically have a new feature change from the previous generation. In the case of the lawn tractor the above data was for 42 inch cut. If the next generation is a 44 or 46 Hp. inch cut than the above model is probably not a good predictor.

Breaking the product into major sub-assemblies and repeating the above process will enable you to great a more accurate cost as various subassemblies are improved or changed from the previous generation.

There are other factors that can be incorporated such as raw material cost and product release dates. A detailed discussion of cost estimating and cost estimating philosophies can be found in paper cited in footnote. [5]

The Levels of Analysis Accuracy[6]

Level 1 or Parametric

This is the proverbially “quick and dirty” method to cost analysis. It relies on previous experience with the general product type, and the application of macro product cost models to generate a ballpark estimate. The macro models would be on the order of cost per attribute (e.g. Cost/lb, Cost/in^3, Cost/Watt, etc…). The time to complete is on the order of about 1-4 hours to gather sufficient information, and apply the macro models.

The accuracy of this method is only about 10-30%, and it directly related to the experience of the estimator. Before beginning any Level 3 analysis we generate a Level 1 estimate to track how good we are. Typically we are within 20% in most estimates but the skew of error is quite high.

Level 2 or By Analogy

This is the analytical method of cost analysis. It relies on previous experience with the particular product type or other members in the same vendor’s product family. It also uses either;

Product feature cost models such as Cost per memory slot, Cost per Disk Drive Bay, Cost per cubic inch for the enclosure, and others as seen on other product family members. It then aggregates up all the feature costs to make a total estimate.

– OR –

Significant part cost analysis - On most designs there are a handful of parts that account for 80% of the total as-designed cost. This method tries to identify the cost drivers, get estimates for those parts and use allowances for the rest of the system.

The accuracy of this method is only about 5-15%, and it is directly related to the how much information you have managed to gather about the product to correctly characterize either features or major cost elements. The time to complete this analysis is on the order of 2-5 days. We most often use this form of estimate for marketing estimates or competitive bid estimates when full access to competitive hardware is not available.

Level 3 or Engineered

The most accurate method for cost analysis requires the product to be physically analyzed. Here we characterize each part – in terms of identity (e.g. part number, vendor, option,..) and/or physical characteristic (weight, size, material type, tooling, …). Next we assess which parts make up the top 80% of cost. We then cost estimate those parts using tools like the Boothroyd and Dewhurst DFM suite of tools. The rest of the parts we use simplified estimates, volume derated catalog cost or quotes from vendors. This method takes 3-4 weeks to complete but yields the truest estimate.

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[5] David, Meeker “Cost Estimating: What is it? How do you do it? What can it do for you?”, 27th International DFMA Conference, Warwick RI. June 2012

[6] Definitions were created by personal conversation with Neil Albert, then President of SCEA a friend and former colleague. See The Society of Cost Estimation & Analysis http://users.erols.com/scea/

The accuracy of this method is only about 3-7%. We do fewer of these evaluations because of their cost in terms of money and resources, but they provide the anchor points to our experience.

Cost the Product

Using a variety of tools and methods we construct an indented, costed Bill of Material (BOM) reflecting each part and subassembly.

Boothroyd and Dewhurst (B&D) tools have been used for sheet metal, injection molded, die cast and machined parts. The size and feature data taken during the physical teardown are fed into software along with the volume expectation from the literature search. Through our corporate purchasing department we have obtained representative labor and raw material rates from most fabrication locations that we use in the tools. Tooling type (e.g. hard, soft, ..) is usually determined by examination of the part and input into the B&D tool. If we can't determine the tooling type visually, we make assumptions based on the expected volume. We report incremental piece part cost and tooling separately as parts of this corporation treat tooling cost as a program overhead cost and other parts of this corporation amortize tooling over the life of the build.

For Printed Wiring Boards (PWB) we use an internally developed tool to estimate PWB costs. Previously we used to a fairly complex tool we bought from BPA, but found that supply cost variations drove the final price more than technical complexity factors.

Assembly time is estimated using Boothroyd and Dewhurst DFMA® software, using a partially loaded labor rate. Test Labor is estimated using the test time of similarly complex internal products, again using a partially loaded labor rate.

Develop Metrics

Once we have determined the unit cost, we sort the cost along several lines, such as function (i.e. CPU, Memory, I/O, Power, Enclosure, etc…), part type (IC, Resistor, Metal Fab, Molded Plastic, etc..), and make/buy. This gives us cost per function, cost by part type, and percentage make/buy. This is the data that is used to help create the Early Product and Product Subassembly equations.

Vendor Quotes

The DFMA tool has a widely known track record on providing detail analysis of part estimates that can be used to compare to vendor quotes. When there is a discrepancy between a vendor quote and the estimate the DFMA tool services a great vehicle to start a dialog with the vendor. The critical part that many companies forget to do is to take the learning from these discussions and feed it back into the DFMA tool to make improvements in the data bases and also feed the learning's back to design engineering. The ultimate evolution of this process can be found in the vendors actually submitting their quotes using the DFMA tool.

The BIGGEST driver of overall impact in the use of the DFMA process/ tool is the aggressive use of Theoretical Minimum Part Count (TMPC). TMPC is the most effective cost reduction tool because it attacks the main driver of cost on products namely parts and subassemblies. By eliminating parts, subassemblies, and processes direct cost is eliminated as well as labor, and a whole host of indirect cost like drawings, tooling, inventory, inventory space, part sourcing and qualification, and less time spend designing parts – to name a few

Outsourcing to the Far East

The author has involved in successful outsourcing projects that have strengthened their many companies, but have also seen outsourcing decisions made that damaged the competitive ability of a company. [7] In all cases, better communication and transparency could have prevented erroneous decisions. Improving transparency without employing excessive time or cost is always the challenge. The use of DFMA process / tool often results in product cost reductions that exceed cost reductions gained by going to the Far East. A DFMA analysis points to the salient costs for manufacture and provides a launching point for effective discussions that should be used in any outsourcing to the Far East, NAMELY "total cost of ownership". [8][9]

Classic DFMA design example_ 

When you look at a product design, many of its constituent parts, like brackets, fasteners, and sheet metal trays create internal structure. The only real purpose of the infrastructure is to hold together all the parts and subassemblies that need to be interconnected so that the product will function. As such, these parts are the ones most often highlighted for elimination when the theoretical minimum part count questions are asked. One of the earliest products to employ DFMA and the power of using theoretical part count was the IBM ProPrinter.[10] By using the theoretical minimum part technique as a target, IBM was able to eliminate all the fasteners, brackets and unnecessary pieces of hardware from its ProPrinter. In the ProPrinter, the base tray played a major role in fastener / bracket elimination. After redesign, every part in the ProPrinter fastened to the base tray via a snap fit, and subsequent parts snap fitted into parts already in place. In contrast, Epson's PC printer the MX80 used a lot of hardware to fasten parts and subassemblies together and secure the final product assembly. As a result, the MX80 possessed 111 parts more than theoretical minimum, compared to three for the ProPrinter.

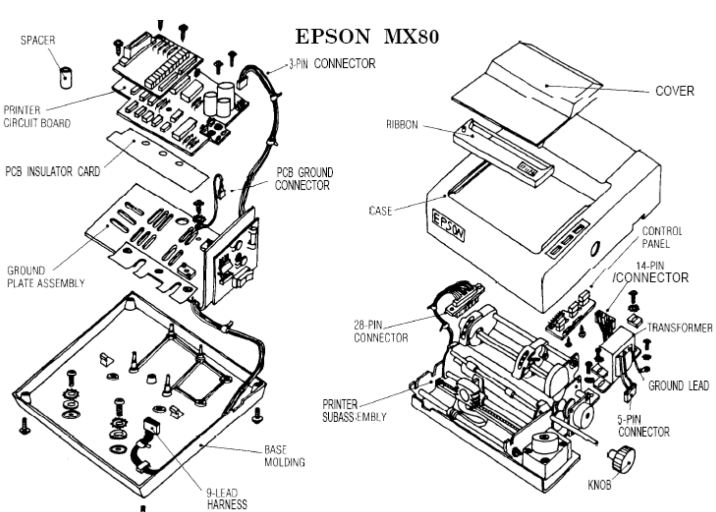

FIG. 1
The EPSON MX80 dot matrix printer final assembly consists of 49 parts or subassemblies as shown in this exploded view.

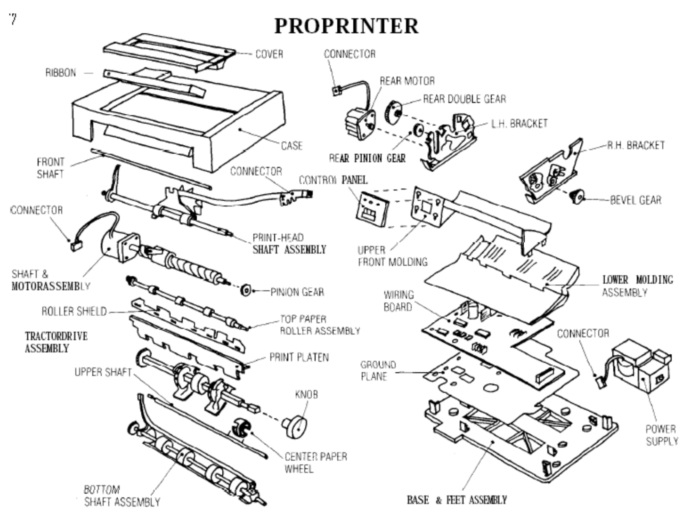

FIG. 5
Exploded view of IBM Proprinter highlights design simplification in this product.

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7 Michael Hiltzil, "787 Dreamliner Teaches Boeing Costly Lesson on Outsourcing," Los Angeles Times, 15 February 2011.

[8] Meeker, David and Nicholas Dewhurst. "The True Cost of Oversea Manufacturing" The 19 th Annual International Conference on DFMA Warwick, RI June (2004)

[9] Meeker,David and Jay Mortenson. "Outsourcing to China: A Case Study Revisited Seven Years Later, The 26th International Conference on DFMA Warwick, RI June 2011

[10] Design for Assembly in Action, Assembly Engineering January 1987

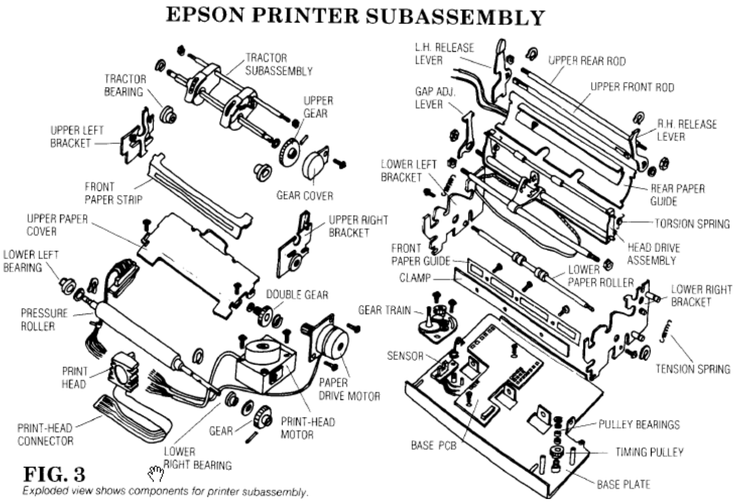


FIG. 3
Exploded view shows components for printer subassembly.

Epson MX 80		**IBM PRO Printer**	
Total Assm. Time sec.	1866.	Total Assm. Time	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

An examination of 117 Industry case studies covering 9 different industry segments:

- Computer
- Consumer goods
- Defense
- Energy
- Equipment
- Medical
- Telecommunications
- Test & Measurement
- Transportation

Average Reductions:

Part Count 54%
Assembly Time.........................60%
Assembly Cost..........................45%
Total Cost 50%
Separate Fasteners..................57%
Assembly Operations 53%
Labor Costs 42%
Assembly Tools 73%
Weight 22%

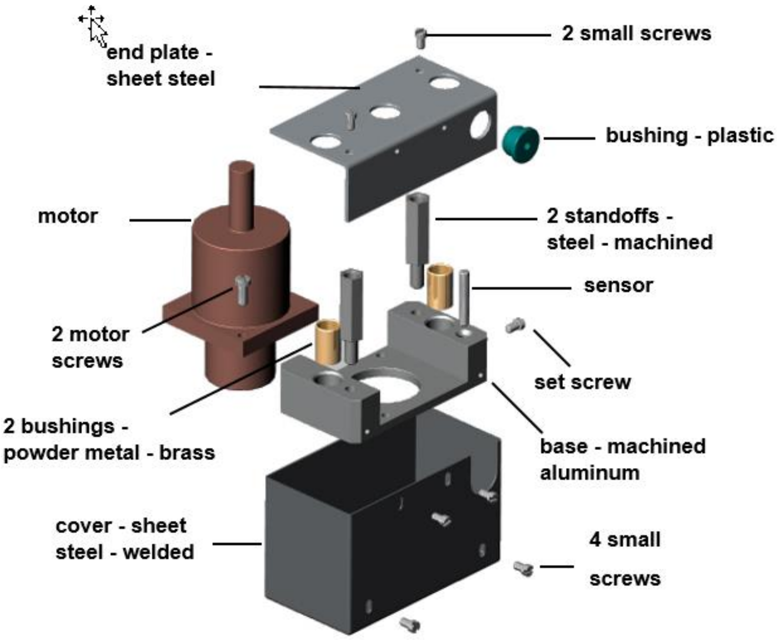
Product Development Cycle.....45%

Note Average part count reduction was 54%. Next is a case study on a real subassembly to demonstrate the power of this concept.[11]

Theoretical Minimum Part Count: Motor Case Study Example,

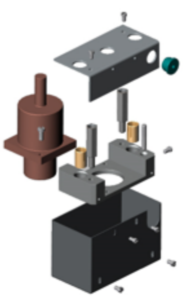
The motor case study is from a real project (Number and Vendors have been altered due to confidentiality issues) – It is the subassembly that senses the distance between calendaring rollers and adjust the distance between them. The original design is picture below:[12]

[11] White Paper – Development of DFMA and its Imapct on U.S. Industry, March 9th , 2000 Wakefield RI., Boothroyd and Dewhurst Inc.
[12] David, Meeker & Nick Dewhurst, " The Best Tool in the Designers Toolbox", 29th International DFMA Conference, Warwick RI., June 2014



Shown below is the Costed BOM for the Motor subassembly

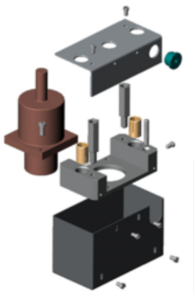
Motor BOM



Category	Part Name	Qty	Part Num	Item Cost ($)		Supplier
Purchased Items						
	Motor	1	616-BDI-03	$	12.55	ACME Motor
	Sensor	1	109-BDI-03	$	1.58	Sensor-Rama
	Plastic Bushing	1	279-BDI-03	$	0.22	Bushings R Us
	Brass Bushings	2	643-BDI-03	$	1.53	Bushings R Us
Manufactured Items						
	Motor Base	1	074-BDI-03	$	16.38	USA Machine
	Standoffs	2	012-BDI-03	$	4.87	USA Machine
	End Plate	1	257-BDI-03	$	1.44	Joe's Sheetmetal
	Cover	1	753-BDI-03	$	2.08	Joe's Sheetmetal
Hardware						
	Cover Screws	4	975-BDI-03	$	0.03	Fasteners, Inc.
	End Plate Screws	2	123-BDI-03	$	0.03	Fasteners, Inc.
	Motor Screws	2	245-BDI-03	$	0.05	Fasteners, Inc.
	Set Screw	1	097-BDI-03	$	0.03	Fasteners, Inc.

Traditional cost reduction methodologies such as the ones discussed in Appendix A Would create a cost estimate for what the Company thinks the parts should cost

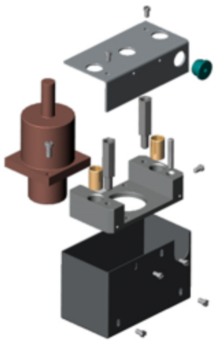
Motor BOM – with Cost Estimate



Part Name	Qty	Part Num	Item Cost ($)	Cost Estimate	Supplier
Motor	1	616-BDI-03	$ 12.55	$ 12.55	ACME Motor
Sensor	1	109-BDI-03	$ 1.58	$ 1.58	Sensor-Rama
Plastic Bushing	1	279-BDI-03	$ 0.22	$ 0.19	Bushings R Us
Brass Bushings	2	643-BDI-03	$ 1.53	$ 1.23	Bushings R Us
Motor Base	1	074-BDI-03	$ 16.38	$ 13.45	USA Machine
Standoffs	2	012-BDI-03	$ 4.87	$ 1.12	USA Machine
End Plate	1	257-BDI-03	$ 1.44	$ 1.22	Joe's Sheetmetal
Cover	1	753-BDI-03	$ 2.08	$ 1.10	Joe's Sheetmetal
Cover Screws	4	975-BDI-03	$ 0.03	$ 0.03	Fasteners, Inc.
End Plate Screws	2	123-BDI-03	$ 0.03	$ 0.05	Fasteners, Inc.
Motor Screws	2	245-BDI-03	$ 0.05	$ 0.03	Fasteners, Inc.
Set Screw	1	097-BDI-03	$ 0.03	$ 0.03	Fasteners, Inc.

This analysis shows opportunity a quick sort show pareto of savings. This is only a listing of potential magnitude and opportunity, the organization still has to go out and get this delta savings. More times not they are not able to achieve the potential magnitude due to issues of supply chain, volume, material pricing, etc………..

Motor BOM – sorted



Part Name	Qty	Part Num	Item Cost ($)	Cost Estimate	Delta
Standoffs	2	012-BDI-03	$ 4.87	$ 1.12	$ 3.75
Motor Base	1	074-BDI-03	$ 16.38	$ 13.45	$ 2.93
Cover	1	753-BDI-03	$ 2.08	$ 1.10	$ 0.98
Brass Bushings	2	643-BDI-03	$ 1.53	$ 1.23	$ 0.30
End Plate	1	257-BDI-03	$ 1.44	$ 1.22	$ 0.22
Plastic Bushing	1	279-BDI-03	$ 0.22	$ 0.19	$ 0.03
Motor	1	616-BDI-03	$ 12.55	$ 12.55	$ -
Sensor	1	109-BDI-03	$ 1.58	$ 1.58	$ -
Cover Screws	4	975-BDI-03	$ 0.03	$ 0.03	$ -
End Plate Screws	2	123-BDI-03	$ 0.03	$ 0.03	$ -
Motor Screws	2	245-BDI-03	$ 0.05	$ 0.05	$ -
Set Screw	1	097-BDI-03	$ 0.03	$ 0.03	$ -

The results shown above;

1. Help save money quickly but are limited by some of the reason listed above.
2. They focus on the most cost savings without changing the design
3. Influence of design change through TMPC can have a much bigger impact.

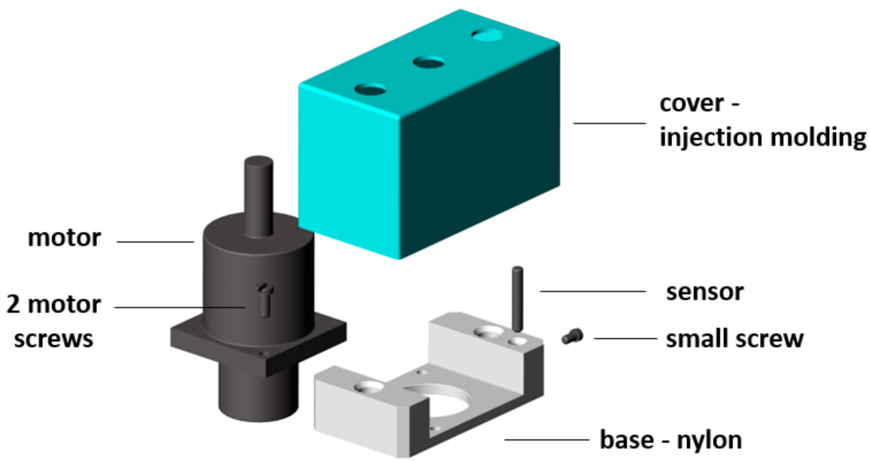
Below is an analysis of the Motor Case using the TMPC questions? As you can see there is a substantial difference between the current design part count and the TMPC target.

Minimum Parts Worksheet

Base	1	Base
Bushings	2	None
Motor	1	Movement
Motor screw	2	Fastener
Standoff	2	None
Sensor	1	Material
Set screw	1	Fastener
End plate	1	Assembly
End plate screw	2	Fastener
Grommet	1	None
Reorientation	1	None
Feed Wires	2	None
Cover	1	None
Cover screws	4	Fastener
Total	22	4 meet theoritical min.

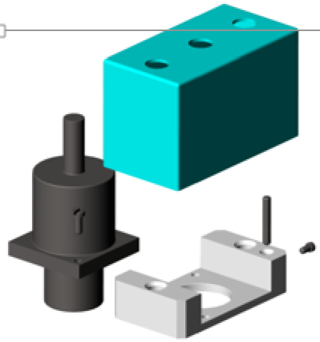
It is now time for the product development team, to earn their pay by creating a new design that attempts to hit the TMPC goal. One resultant design is shown below.

Motor Product Simplification



Resultant Design results in substantial savings (using cost data from above)

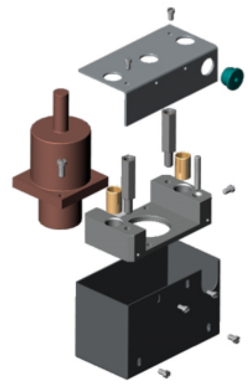
Motor BOM – Design Change

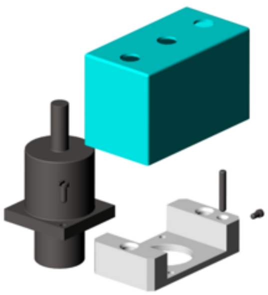


Part Name	Qty	Part Num	Item Cost ($)	Cost Estimate	Supplier
Motor	1	616-BDI-03	$ 12.55	$ 12.55	ACME Motor
Sensor	1	109-BDI-03	$ 1.58	$ 1.58	Sensor-Rama
Motor Base	1	074-BDI-03	$ 16.38	$ 13.45	USA Machine
Cover	1	753-BDI-03	$ 2.08	$ 1.10	Molds R Us
Motor Screws	2	245-BDI-03	$ 0.05	$ 0.03	Fasteners, Inc.
Set Screw	1	097-BDI-03	$ 0.03	$ 0.03	Fasteners, Inc.

The results speak for themselves, these are a few of the major ones but there are also many intangible ones as well.

- 63 percent reduction in parts
- 4 suppliers removed from supply chain
- 63 percent reduction in detail drawings
- 74 percent reduction in assembly time
- Equal reduction in labor cost





And let's not forget….

46% Reduction in Total Cost of the product

Conclusions:

For 30 years DFMA process and analysis tool has been out in industry helping designers optimize and refine their products. Because of the simplicity of its process, and tool structure it can be utilized from product concept through product end of life. Faithful practitioners have over the years expanded its capabilities and area of usage. In the final analysis of bang for the buck it offers, for total cost of investment the best return of any of the design analysis tool out there.

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

Antoine de St. Exupery

(1900-1944)