DESIGN FOR MANUFACTURE AND ASSEMBLY

History, an overview, and a design story

Nicholas P Dewhurst

Boothroyd Dewhurst, Inc. 2019

October 1st, 2019

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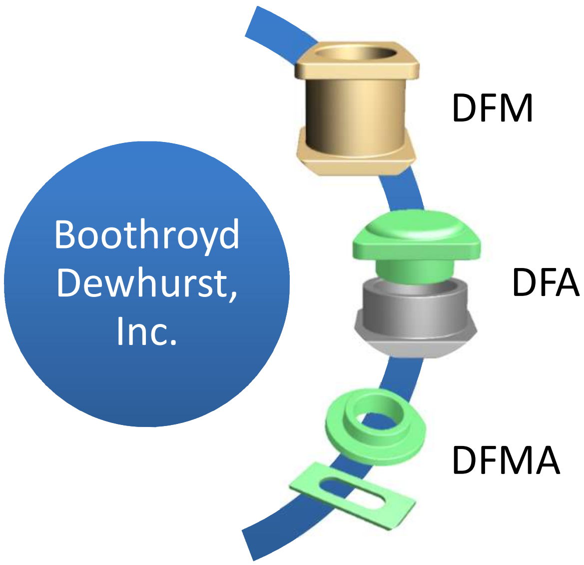
- Degree in Mechanical Engineering and Applied Mechanics
- Help clients understand the benefits of DFMA
- Apply DFMA to products on a consulting basis
- Helped companies around the world make DFMA part of their product development process

Boothroyd Dewhurst, Inc.

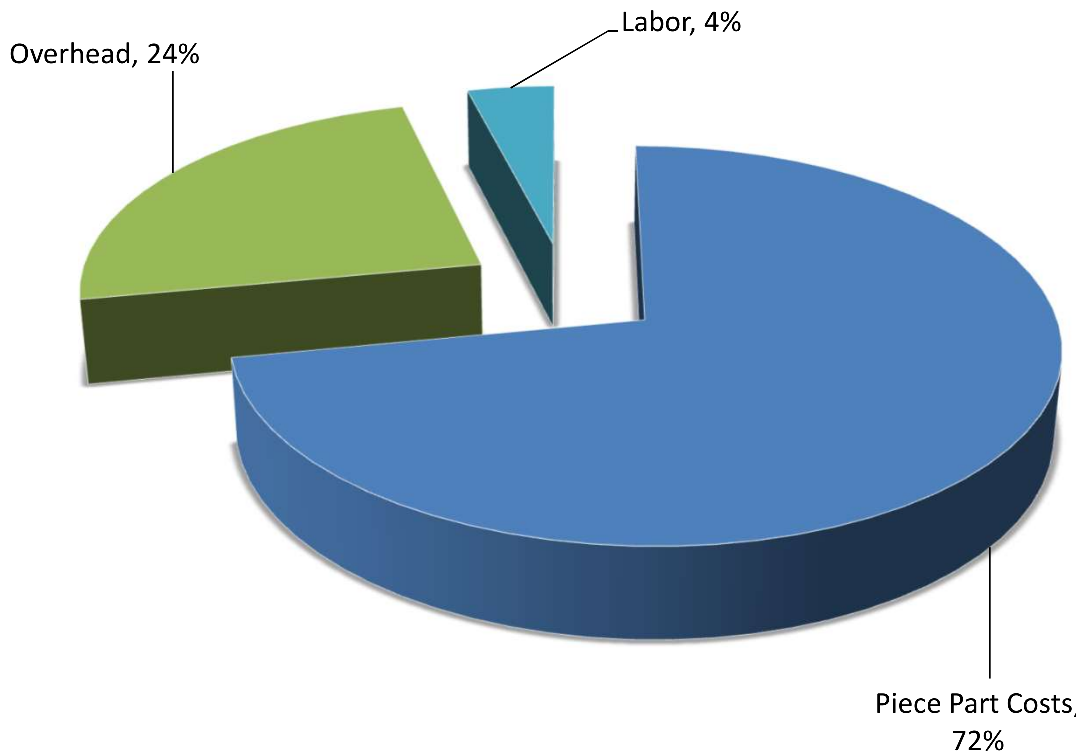
- Founded in 1981
- First Software in 1983
- 850 Companies from broad range of industries
- 1991 Winner of National Medal of Technology
- R&D continues today with new cost model development, new software interface design, and updated databases

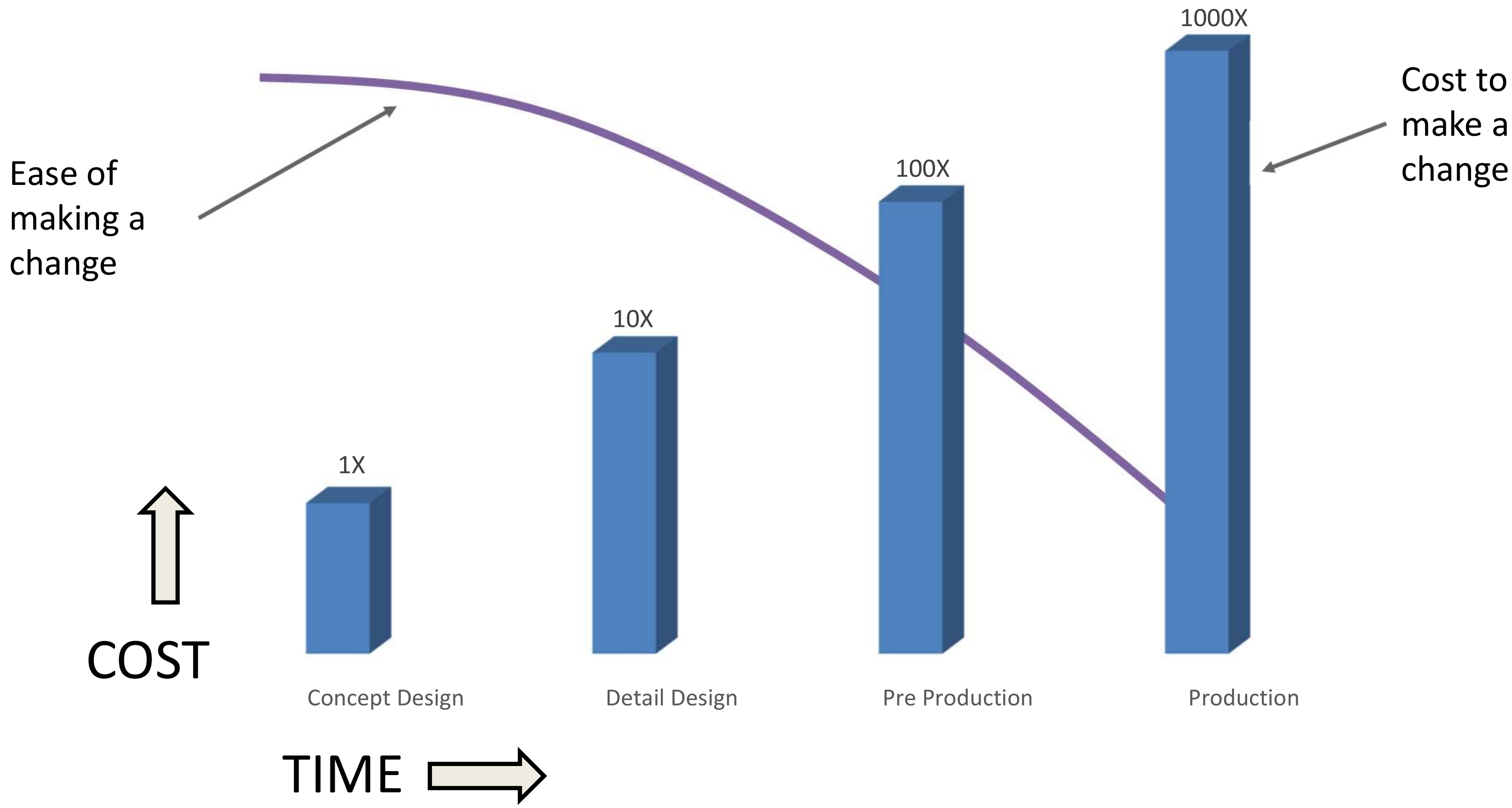
What is DFMA?



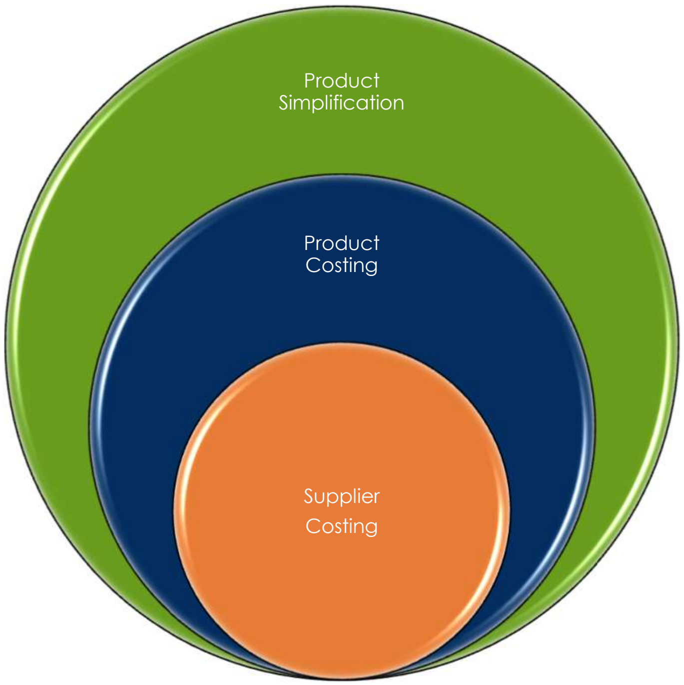
A suite of tools used to analyze and understand the cost of a product's design and its constituent parts.

Typical Product Cost Breakdown





Where should your focus be?



PRODUCT SIMPLIFICATION

Our real time approach to product simplification unlocks the potential for part count reduction within your assemblies

PRODUCT COSTING

Looking at the alternative process and/ or material combinations that may lead to potential piece part cost savings

SUPPLIER COSTING

Using the outputs from our DFMA software to better negotiate price in a real time fashion

The Three main uses of DFMA

Sample Case study

Supplier Negotiations

"According to our Product Management team we will sell 190,000 of these clips a year. So, it seems that the software helped us to negotiate a savings of $361,000 on this one item."

-VP of Engineering at a leading electronics company, May 2014

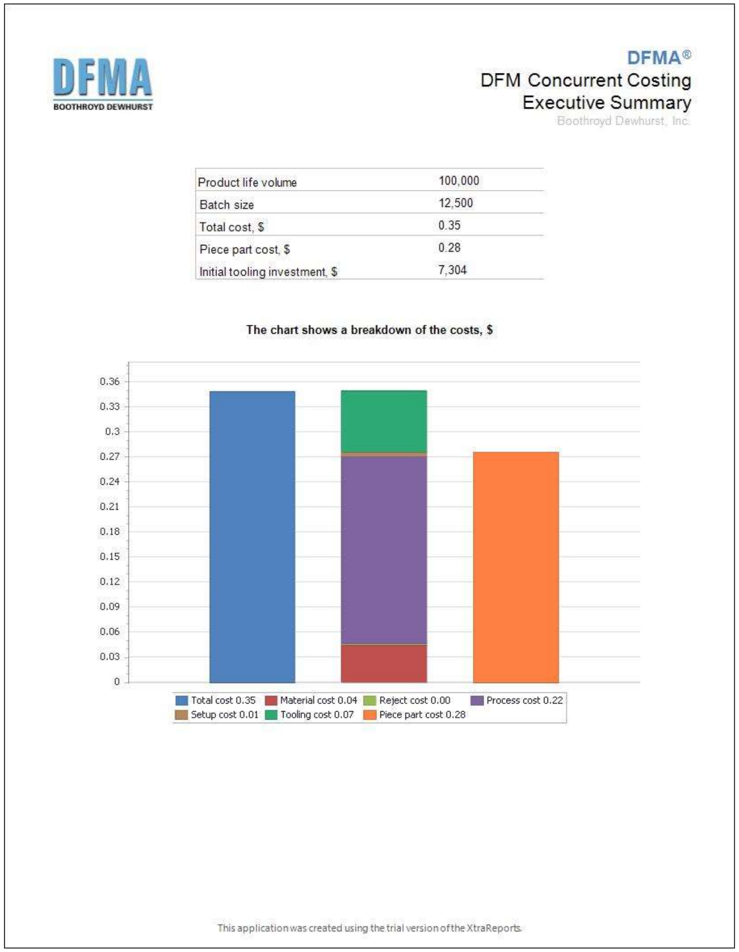
Challenge

Needed young project engineers to more actively support negotiations on high production volume products to ensure best possible price.

Solution

Use DFMA analysis to aide in the negotiation and apply information gathered from initial discussion to improve cost estimate accuracy in real time

Cost Result


DFMA
BOOTHROYD DEWHURST

DFMA®
DFM Concurrent Costing
Executive Summary
Boothroyd Dewhurst, Inc.

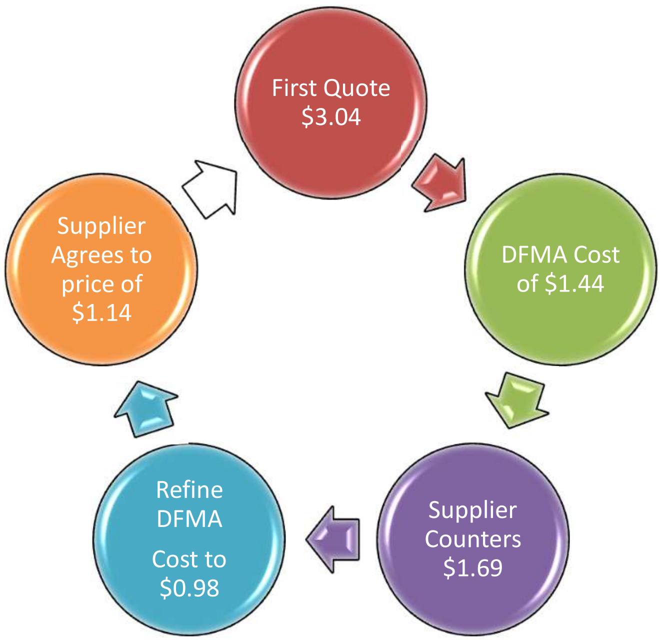
Product life volume	100,000
Batch size	12,500
Total cost, $	0.35
Piece part cost, $	0.28
Initial tooling investment, $	7,304

The chart shows a breakdown of the costs, $

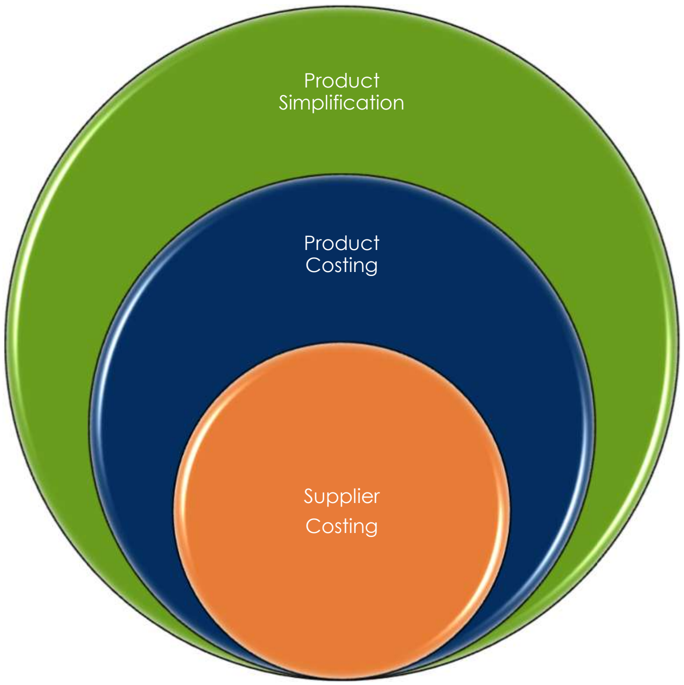
This application was created using the trial version of the XtraReports.

- Cost of $0.35 per part
- We get a detailed breakdown of the cost drivers
- Material
- Setup
- Process
- Rejects
- Tooling

Results – plastic clip assembly



- Annual Production Volume of 190,000
- ROI on software investment achieved on this single example
- Cost avoidance of $361,000 annually



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Decisions decisions decisions, what's a designer to do?

Part and manufacturing level decisions; “Product Costing”

- Cost is too high
- Corrosion is a problem
- Bending stiffness is critical and must be maintained
- Paint it, but what is the added cost?
- Might the paint crack around the mounting hole and allow for corrosion to begin?
- Make it from stainless, but what would that add in terms of cost?
- Make it from plastic but what would the tooling investment be and would we be able to maintain the stiffness requirement?

24 gage (0.61 mm) thick steel:

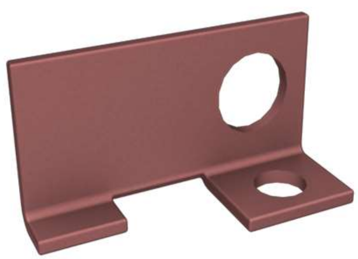
Alternative Designs

$A

24 gage (0.61 mm) thick steel

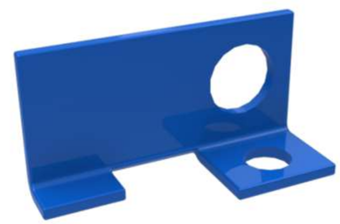
$C

stainless steel



$B

24 gage (0.61 mm) thick steel painted



$D

Injection molded

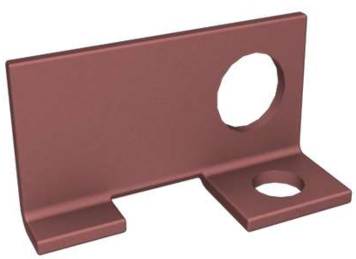
Cost of alternatives

$0.75

24 gage (0.61 mm) thick steel

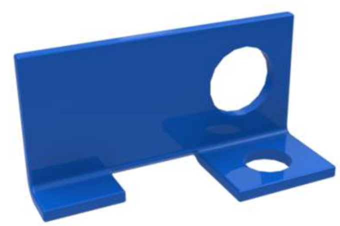
$2.42

stainless steel



$1.31

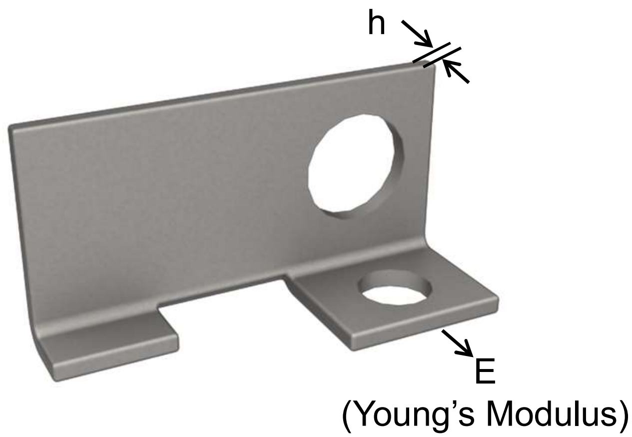
24 gage (0.61 mm) thick steel
painted



$0.61

Injection molded (commodity resin)

Injection Molding example



Bending stiffness depends upon E h^3

For equivalent stiffness of materials 1 and 2

$$E_2 \, h_2^3 = E_1 \, h_1^3$$
$$\text{or } h_2 = h_1 \, (E_1/E_2)^{1/3}$$

Thickness with equivalent stiffness to 24 gage (0.61 mm) thick steel:

Polyethylene; $h = 0.61\ (207{,}000/925)^{1/3}$
$= 3.7$ mm

ABS; $h = 0.61\ (207{,}000/2{,}100)^{1/3}$
$= 2.8$ mm

Polycarbonate (30% glass); $h = 0.61\ (207{,}000/5{,}500)^{1/3}$
$= 2.0$ mm

Injection Molding example

Polymer Processing Data

Thermoplastic	Thermal diffusivity, $\propto$(mm^2/s)	Injection temp., T_i (°C)	Mold temp., T_m (°C)	Ejection temp., T_x (°C)
H.D. polyethylene	0.11	232	27	52
Polypropylene (40% talc)	0.08	218	38	88
ABS	0.13	260	54	82
6/6 Nylon	0.10	291	91	129
Polycarbonate	0.13	302	91	127
Polycarbonate (30% glass)	0.13	329	102	141

Injection Molding example

$$t_c = 4 + 15\,(\,w_t - 0.1\,) + kh^2$$

where w_t = shot weight, kg

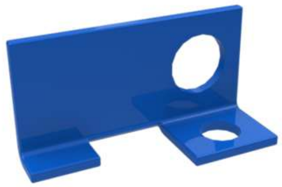
$$k = \frac{1}{\Pi^2 \propto} \log_e \frac{4\,(T_i - T_m)}{\Pi\,(T_x - T_m)} \text{ sec.}$$

h = maximum wall thickness, mm

Examples

Polyethylene;	$k = 2.16$ sec/mm^2
ABS;	$k = 1.74$ sec/mm^2
PC (30% glass);	$k = 1.56$ sec/mm^2
PP (40% talc);	$k = 1.93$ sec/mm^2

Injection Molding example

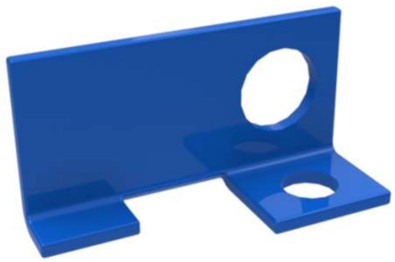


Criterion: Equivalent bending stiffness to 24 gage steel (0.61 mm)

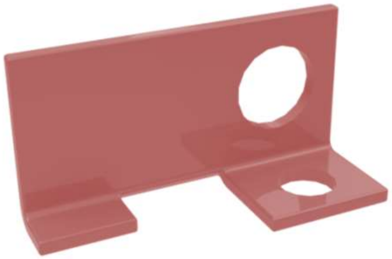
Material	Thickness (mm)	Cooling time (sec)	Process cost*
Polyethylene	3.7	29.6	$0.68
ABS	2.8	13.6	$0.31
PC (30% glass)	2.0	6.2	$0.14

** based on same machine; cooling time only*

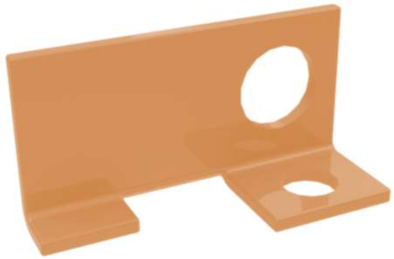
Injection Molding example material costs



2.0mm Wall Thickness
30% Glass PC
$2.60 / Lb.

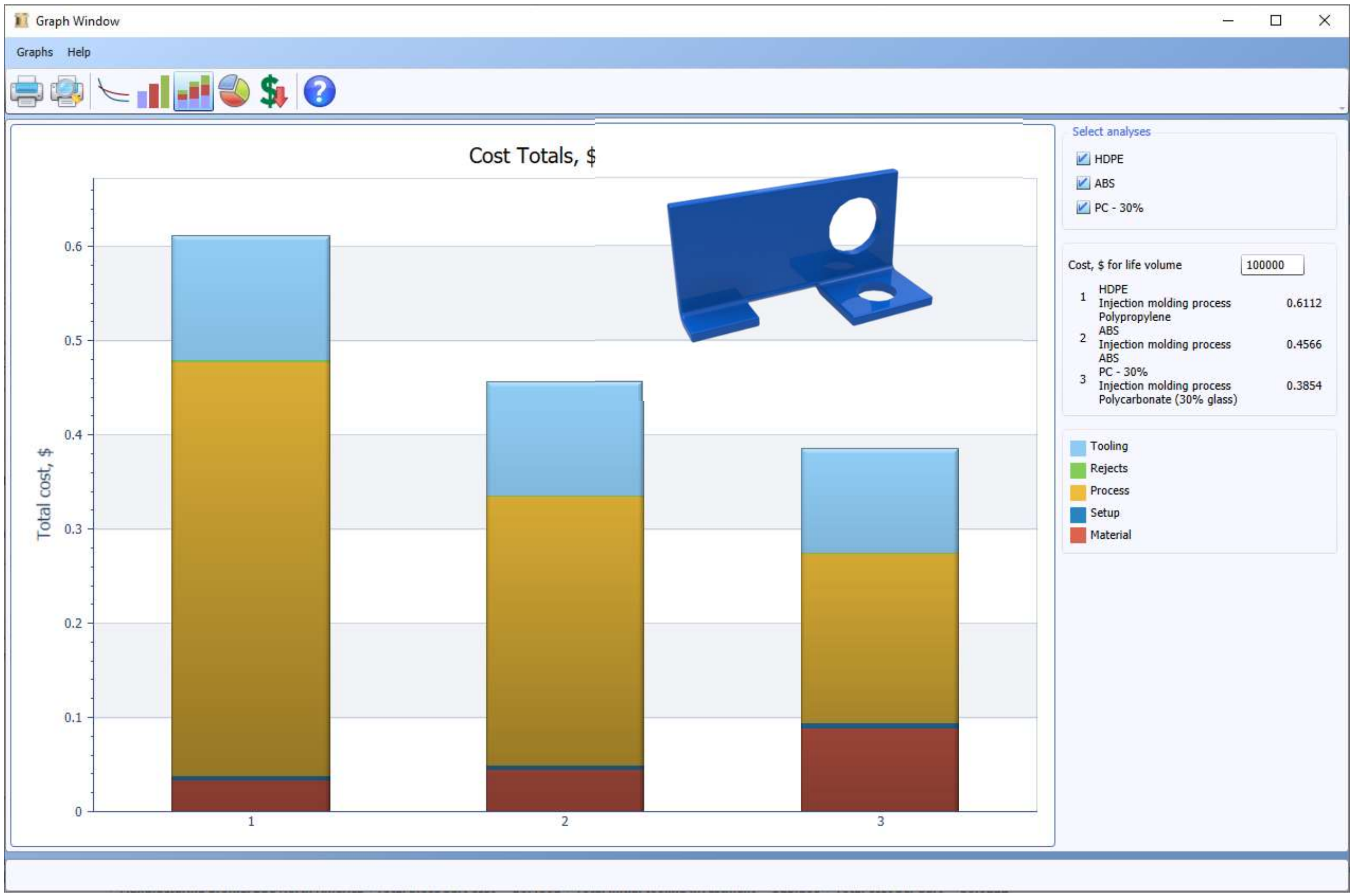


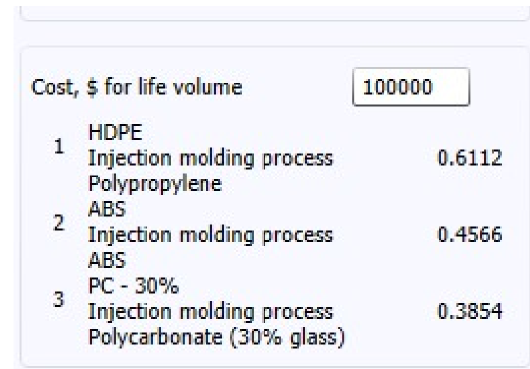
2.8mm Wall Thickness
ABS
$1.55 / Lb.



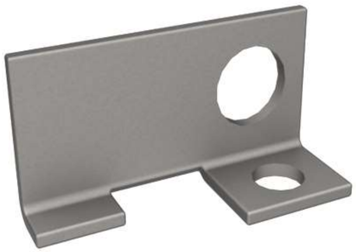
3.7mm Wall Thickness
Polyethylene
$0.95 / Lb.

Injection Molding example





Final Design Decision Result

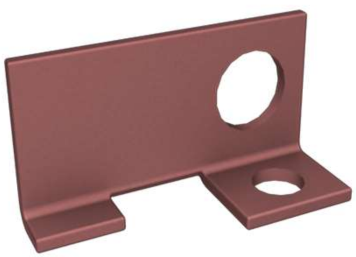


$0.75

24 gage (0.61 mm) thick steel

$2.42

stainless steel



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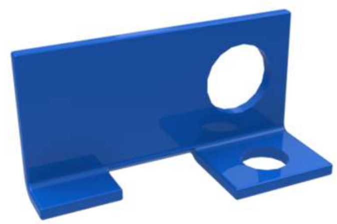
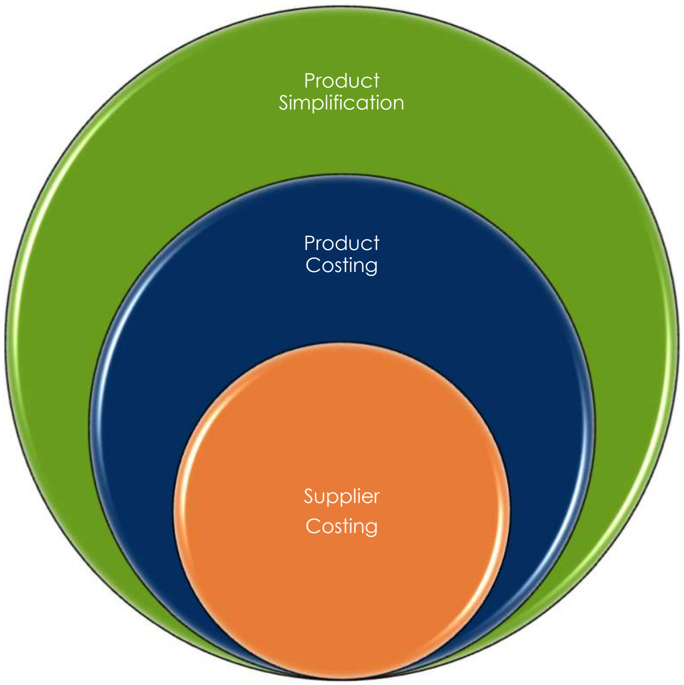


$0.61

$0.39

Includes amortized tooling cost

Injection molded



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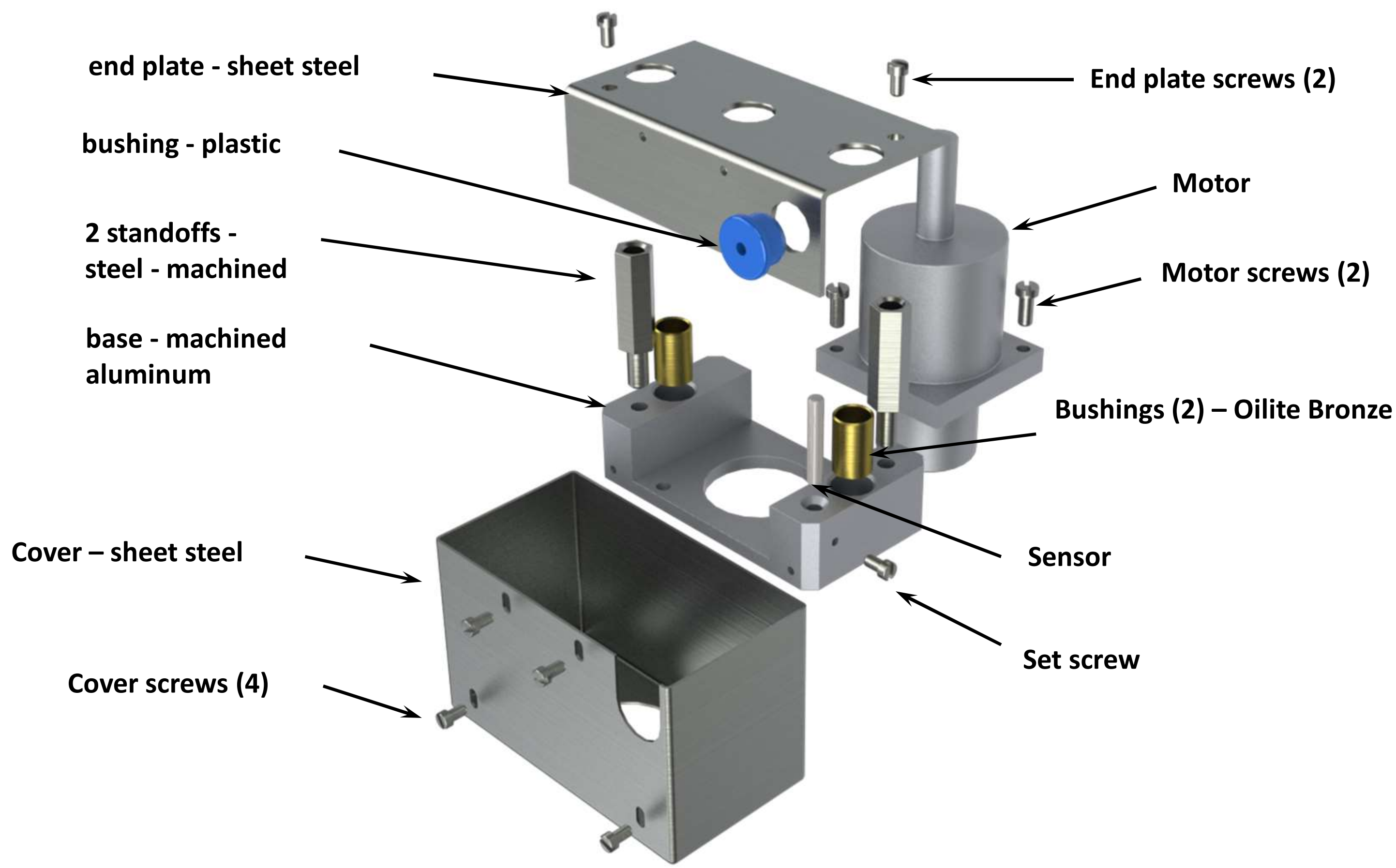
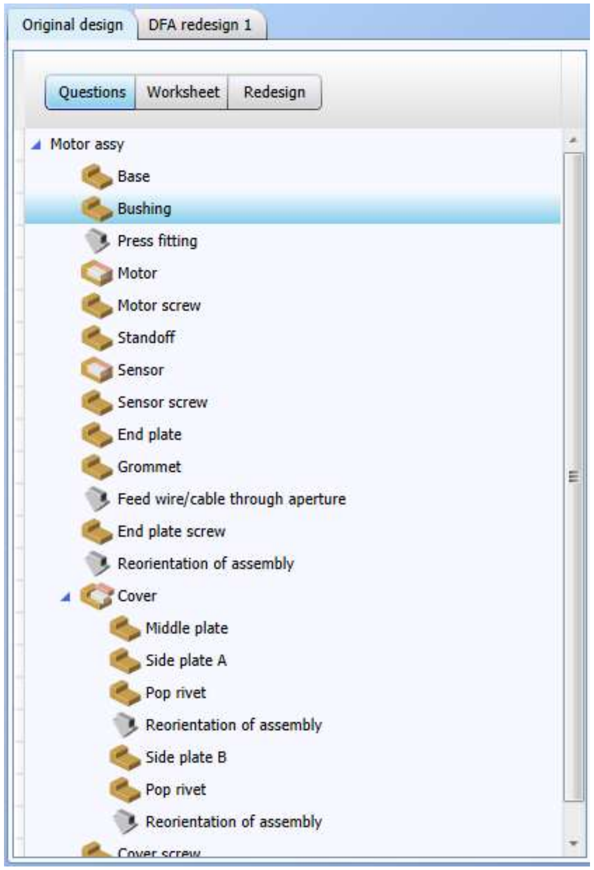
DFA as a design decision tool

- Guides a team through a series of steps to ensure part count efficiency
- Simply changes rarely have dramatic impacts on cost
- People are generally risk averse and making significant changes is difficult
- Better to implement early in the design process so there isn't as much to change
- Payoff in upfront design time is tremendous, you just have to believe



DFMA: Product Simplification

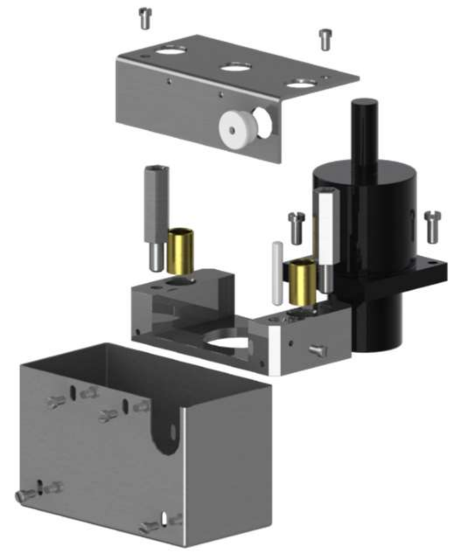


Minimum Part Criteria

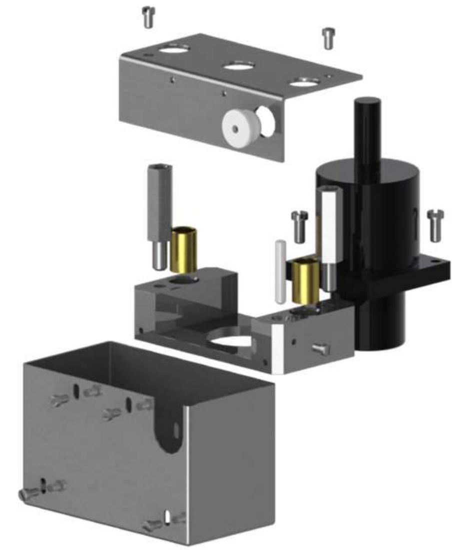
- Base Part / Chassis
- Fastening Function
- Connecting Function
- Different Material
- Relative Movement
- Assembly of Other Items

Handling & Insertion Difficulties

- Envelope Size
- Part Symmetry
- Alignment
- Nest or Tangle
- Other Restrictions, etc.



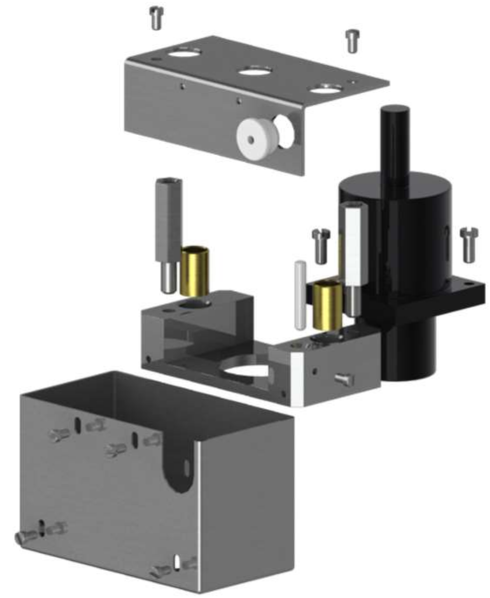
Product Simplification

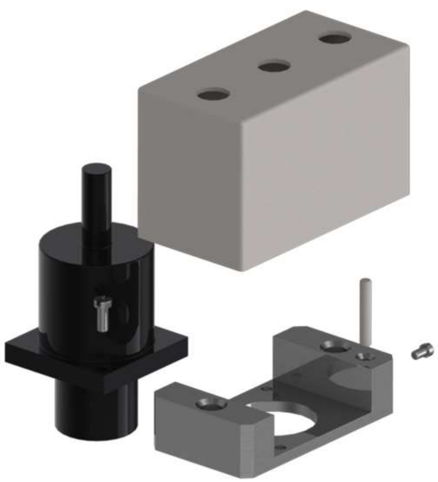


Product Simplification - Analysis

DFA Analysis Results

- 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 assembly labor cost





And let's not forget….

46% Reduction in Total Cost of the product

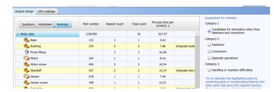
1 Project Scope & Definition

- Representative products, subassemblies or competitive units selected for baseline analysis
- Tear down or assembly sequence catalogued leveraging industry-leading DFMA® tools

3a DFA Opportunity Classification

Leverage DFA suggestions for redesign to generate ideas around:

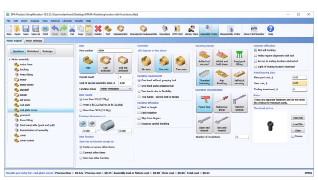
- Product simplification
- Ease of assembly
- Cost reduction / avoidance
- Classify redesign risk into Safe, Reach, and Stretch categories



1 Project Scope & Definition → 2 Baseline Analysis → 3a DFA Opportunity Classification / 3b DFM Cost Estimation → 4 Results Implementation

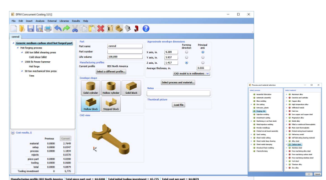
2 Baseline Analysis

- Capture assembly details using intuitive Design for Assembly (DFA) tool
- Answer minimum part criteria questions to arrive at theoretical minimum part count



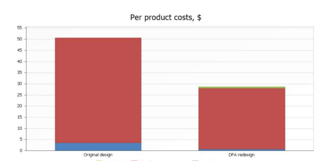
3b DFM Cost Estimation

- Generate forensic cost estimates using Design for Manufacture (DFM) for each component part to provide a "should cost" that can be compared to actual component part spend

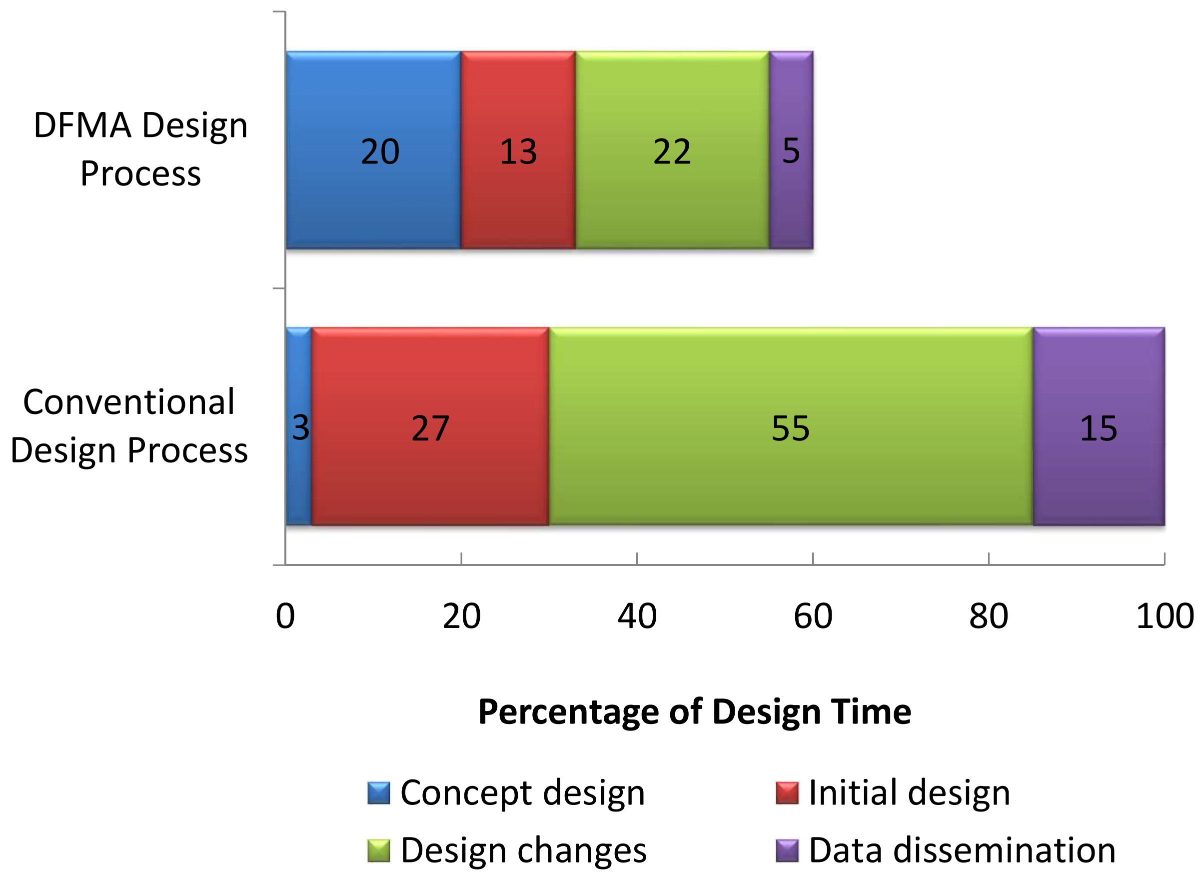


4 Results Implementation

- Quantify ideas generated from DFMA® total cost estimation and define roles and responsibilities for redesign implementation



DFMA's Impact on Design Cycle



Source: *Plastics Design Forum*

Average DFMA Cost Reductions

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

Top ten responses quoted from over 170 case studies

(Presented in order of most commonly quoted responses)

Summary & Conclusions

- Cost information in the hands of purchasing is invaluable
- Trade offs in part design, manufacture, and material must be considered early in the development process
- Time to design 'simple' parts individually is less than more complex ones
- Cost impact of products made from lots of 'simple' parts can be significant
- Tooling investments are often seen as a barrier to entry but true understanding of actual costs are rare
- Cost of production of products made from 'simple' parts are surprisingly high
- Labor impact on production is usually not the focus but can sway decision making
- Cost tools should really be a requirement in the design decision process
- If you aren't using cost to make design decisions you really should
- Have engineers justify the cost of their designs

DESIGN FOR MANUFACTURE AND ASSEMBLY ANALYSIS

A Design Story

Nicholas P Dewhurst

Boothroyd Dewhurst, Inc. 2019

October 1st, 2019

What's this story about

- Always looking for small simple products to analyze for examples
- Stumbled on this product years ago
- It has been redesigned over the years and I've kept up with it
- Makes a great DFMA example
- Allows for the calculation of total product cost
- This is a study of the evolution of this design

OFF! Clip•On

Released in 2008

Released in 2013

Released in 2017

OFF! Clip•On Original Design

Original Design

- Made in 2008
- Weighs 7.1 oz (Packaged weight)
- Measures 7.4” x 5.5” x 2.25” (Packaged dimensions)
- Uses two AA batteries
- Purchase price $8.94

OFF! Clip•On Redesign A

Redesign A

- Made in 2013
- Weighs 4.3 oz (Packaged weight)
- Measures 5.75” x 4.75” x 1.75” (Packaged dimensions)
- Uses two AAA batteries
- Purchase price $8.20

OFF! Clip•On Redesign B

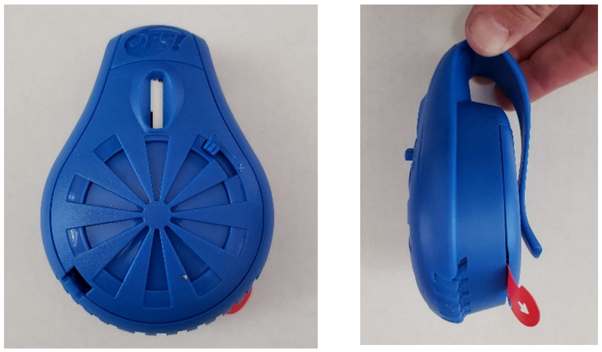
Redesign B

- Made in 2017
- Weighs 4.0 oz (Packaged weight)
- Measures 5.5” x 4.625” x 2.00” (Packaged dimensions)
- Uses two AAA batteries
- Purchase price $7.94

2008

2013

2017



$8.94

$8.20

$7.94

- What are the manufacturing costs?
- Has it been profitable?
- Are there any interesting design features that have been employed?
- Have they improved over the years?
- What improvements have been made?
- What might have influenced some of the product changes?
- Could things have been done better or differently?

Original Design - comments

- Unit feels heavy
- All one color
- Plastic feels thick and substantial
- Packaging is ‘complex’
  - Several inserts (coupon, instructions, etc.)
  - Large multi color printed cardboard
  - Relatively large clam shell package
- Simple, intuitive operation
- Simple to replace batteries
- Belt clip is fixed
- Belt clip is secured with a snap fit

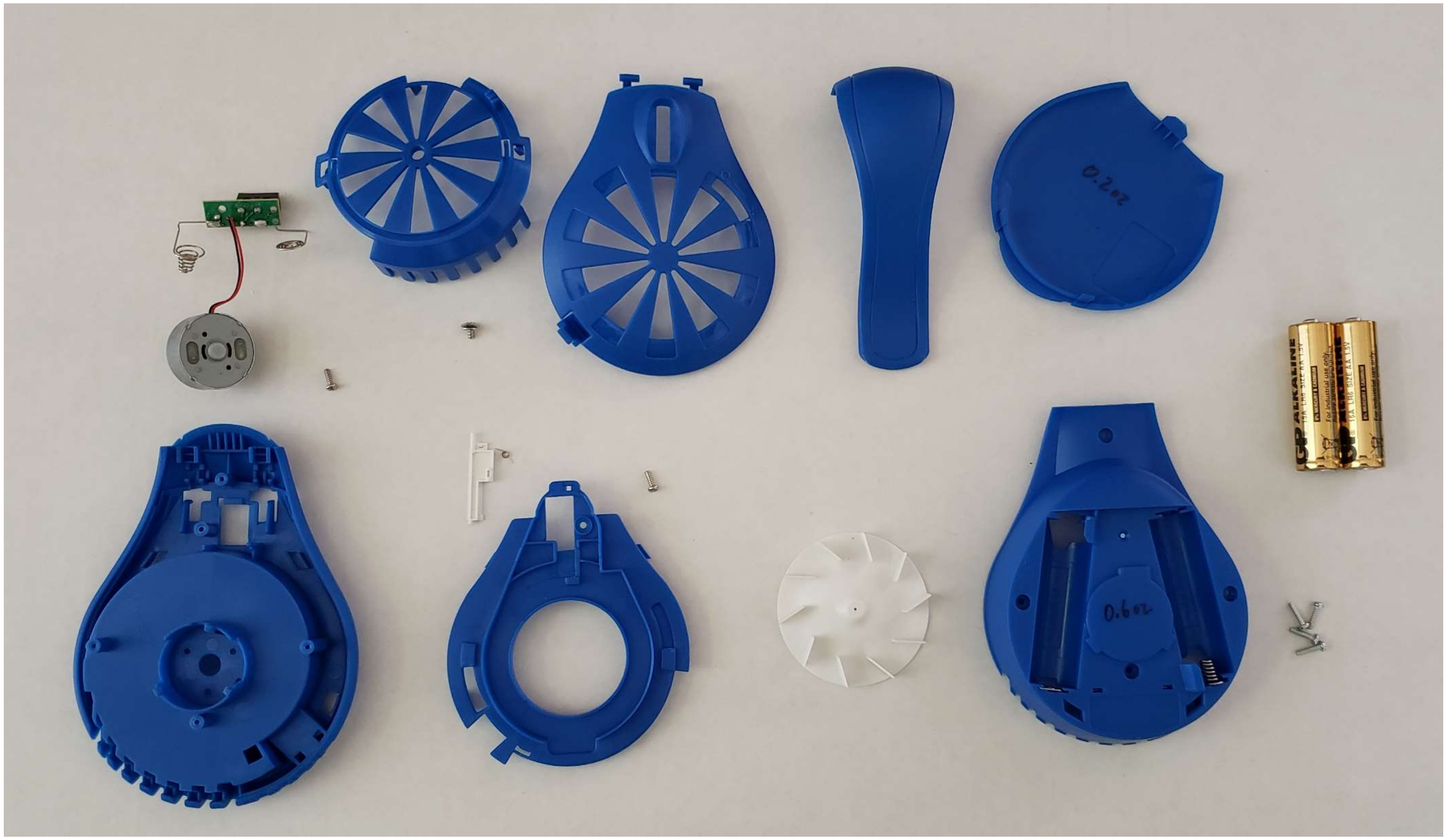
Redesign A - comments

- Smaller lighter weight unit
- Now in two colors
- Plastic feels less thick but still substantial
- Packaging is smaller and more simple
  - No inserts
  - Smaller cardboard inserts but still two and with color printing
  - Smaller clam shell plastic package
- Simple, intuitive operation
- Simple to replace batteries
- Belt clip now rotates
- Uses AAA batteries rather than AA in original

Redesign B - Comments

- Unit is smaller still
- Now in three colors
- Plastic feels less thin, almost too thin
- Packaging is smaller and even more simple
  - Cardboard outside is part of the package
  - Two color printing on outside packaging still
  - Smaller simple thermoformed cup stuck to plastic
- Operation is simple but seems a little less intuitive
- Simple to replace batteries
- Belt clip still rotates
- Unit now incorporates an LED to show its on / low battery
- Still uses AAA batteries

Original Design Exploded View



DFMA Analysis Summary - Original

Entries including repeats	Original
Parts meet minimum part criteria	11
Parts are candidates for elimination	13
Analyzed subassemblies	3
Separate assembly operations	9
Total entries	36

Assembly labor time, s	
Parts meet minimum part criteria	60.44
Parts are candidates for elimination	92.69
Insertion of analyzed subassemblies	27.26
Separate assembly operations	60.75
Total assembly labor time	241.14

Design efficiency	
DFA Index	16.52

Per product costs, $	Original
Assembly process	0.48
Manufacturing piece part	3.70
Total cost without tooling	4.18
Total tooling cost	0.10
Total cost	4.28

Total tooling investment, $	
Assembly tools and fixtures	0
Manufacturing tooling	101,101
Total investment	101,101

Production life data and weight	
Life volume	1,000,000
Total production life cost, $	4,278,624
Total weight, lb	0.17

Redesign A Design Exploded View

DFMA Analysis Summary – Redesign A

Entries including repeats	Redesign A
Parts meet minimum part criteria	11
Parts are candidates for elimination	7
Analyzed subassemblies	3
Separate assembly operations	12
Total entries	33

Assembly labor time, s	
Parts meet minimum part criteria	69.53
Parts are candidates for elimination	46.20
Insertion of analyzed subassemblies	32.73
Separate assembly operations	69.29
Total assembly labor time	217.75

Design efficiency	
DFA Index	18.29

Per product costs, $	Redesign A
Assembly process	0.43
Manufacturing piece part	3.23
Total cost without tooling	3.67
Total tooling cost	0.09
Total cost	3.76

Total tooling investment, $	
Assembly tools and fixtures	0
Manufacturing tooling	91,026
Total investment	91,026

Production life data and weight	
Life volume	1,000,000
Total production life cost, $	3,756,731
Total weight, lb	0.13

Redesign B Design Exploded View

DFMA Analysis Summary – Redesign B

Entries including repeats	Redesign B
Parts meet minimum part criteria	11
Parts are candidates for elimination	20
Analyzed subassemblies	1
Separate assembly operations	19
Total entries	51

Assembly labor time, s	
Parts meet minimum part criteria	65.92
Parts are candidates for elimination	153.90
Insertion of analyzed subassemblies	3.54
Separate assembly operations	116.31
Total assembly labor time	339.68

Design efficiency	
DFA Index	11.73

Per product costs, $	Redesign B
Assembly process	0.67
Manufacturing piece part	3.73
Total cost without tooling	4.40
Total tooling cost	0.07
Total cost	4.47

Total tooling investment, $	
Assembly tools and fixtures	0
Manufacturing tooling	74,787
Total investment	74,787

Production life data and weight	
Life volume	1,000,000
Total production life cost, $	4,473,815
Total weight, lb	0.07

DFA Analysis Comparison

Entries including repeats	Original	Redesign A	Redesign B
Parts meet minimum part criteria	11	11	11
Parts are candidates for elimination	13	7	20
Analyzed subassemblies	3	3	1
Separate assembly operations	9	12	19
Total entries	36	33	51

Assembly labor time, s			
Parts meet minimum part criteria	60.44	69.53	65.92
Parts are candidates for elimination	92.69	46.20	153.90
Insertion of analyzed subassemblies	27.26	32.73	3.54
Separate assembly operations	60.75	69.29	116.31
Total assembly labor time	241.14	217.75	339.68

Design efficiency			
DFA Index	16.52	18.29	11.73

Boothroyd Dewhurst, Inc.

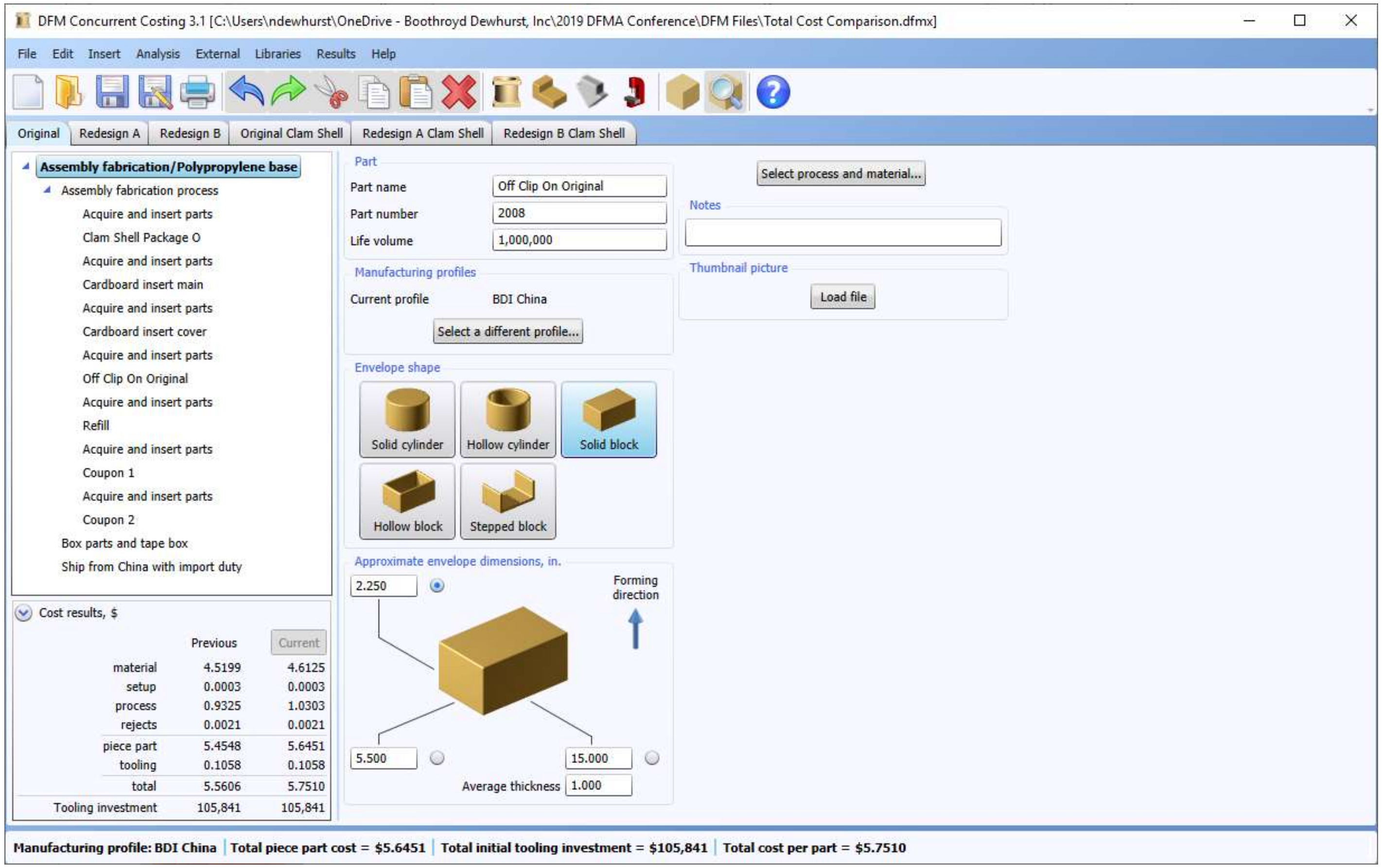
DFMA Analysis Comparison (sort of)

Per product costs, $	**Original**	**Redesign A**	**Redesign B**
Assembly process	0.48	0.43	0.67
Manufacturing piece part	3.70	3.23	3.73
Total cost without tooling	4.18	3.67	4.40
Total tooling cost	0.10	0.09	0.07
Total cost	4.28	3.76	4.47
Total tooling investment, $			
Assembly tools and fixtures	0	0	0
Manufacturing tooling	101,101	91,026	74,787
Total investment	101,101	91,026	74,787
Production life data and weight			
Life volume	1,000,000	1,000,000	1,000,000
Total production life cost, $	4,278,624	3,756,731	4,473,815
Total weight, lb	0.17	0.13	0.07

DFMA Analysis – What's missing

- Packaging Costs
  - Clam shell
  - Boxing for shipping
  - Instructions
- Shipping from China
- Labor for packaging ‘assembly’
- Cost of ‘Refill’

DFMA Analysis – Continued



DFMA Analysis – Total Cost Comparison

		Cost per part, $								
		Life volume	Material	Setup	Process	Rejects	Piece part	Tooling	Total	Initial tooling investment
1	Original Assembly fabrication Polypropylene	1,000,000	4.6125	0.0003	1.0303	0.0021	5.6451	0.1058	5.7510	105,841
2	Redesign A Assembly fabrication Polypropylene	1,000,000	3.9036	0.0003	0.8652	0.0016	4.7708	0.0959	4.8667	95,904
3	Redesign B Assembly fabrication Polypropylene	1,000,000	4.3847	0.0003	1.0796	0.0011	5.4657	0.0794	5.5450	79,361

DFMA Analysis – What's different

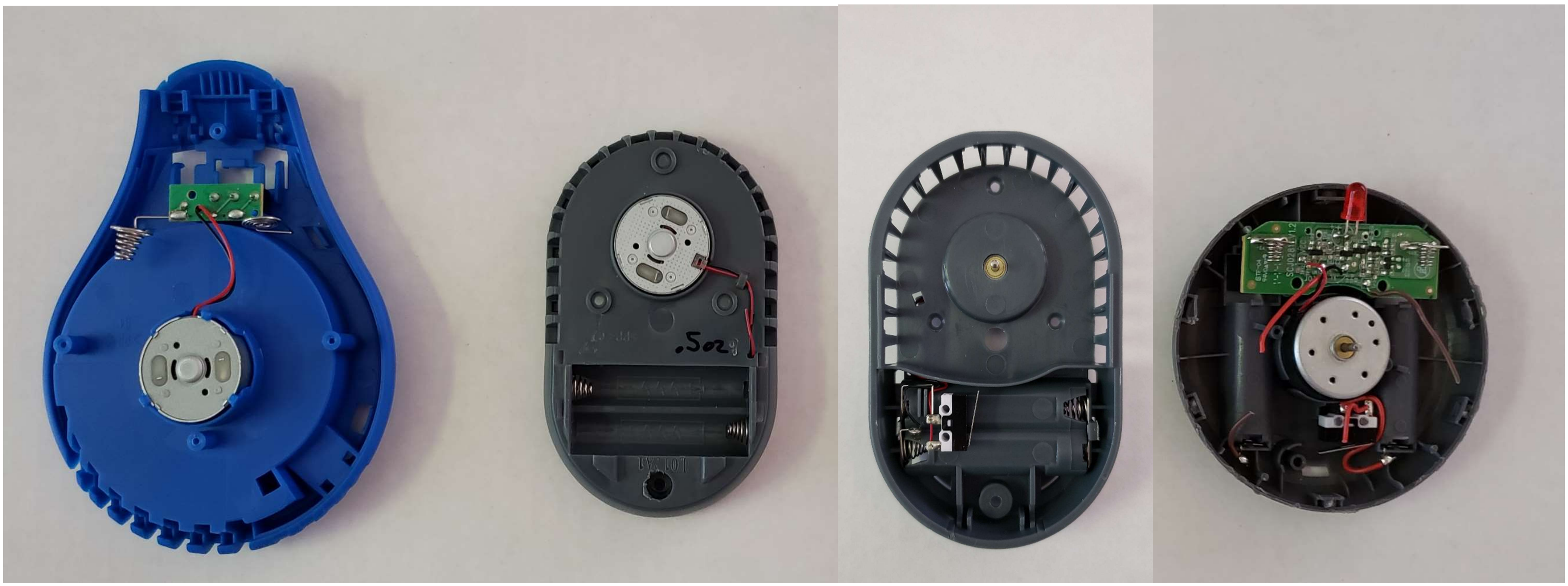
24 Parts, 9 plastic parts, 9 operations

18 Parts, 10 plastic parts, 12 operations

31 Parts, 8 plastic parts, 19 operations

DFMA Analysis – What's different

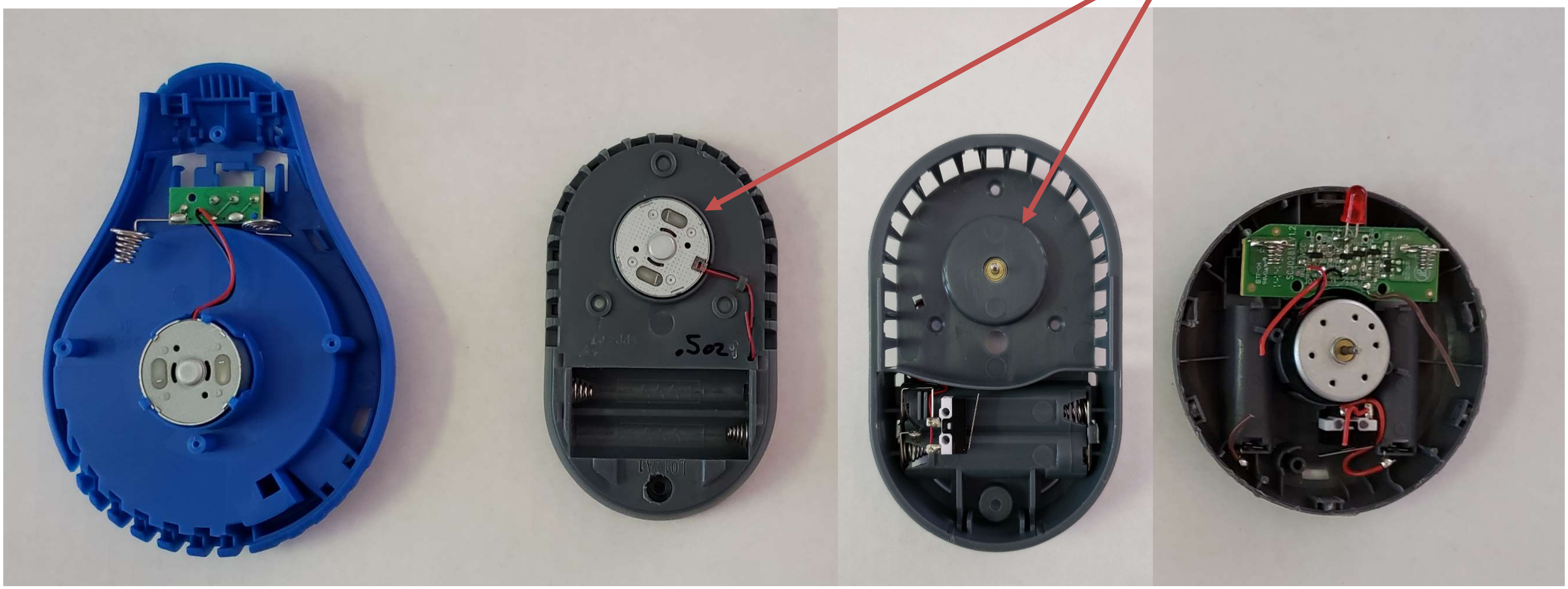
PCB and wiring comparison



DFMA Analysis – What's different

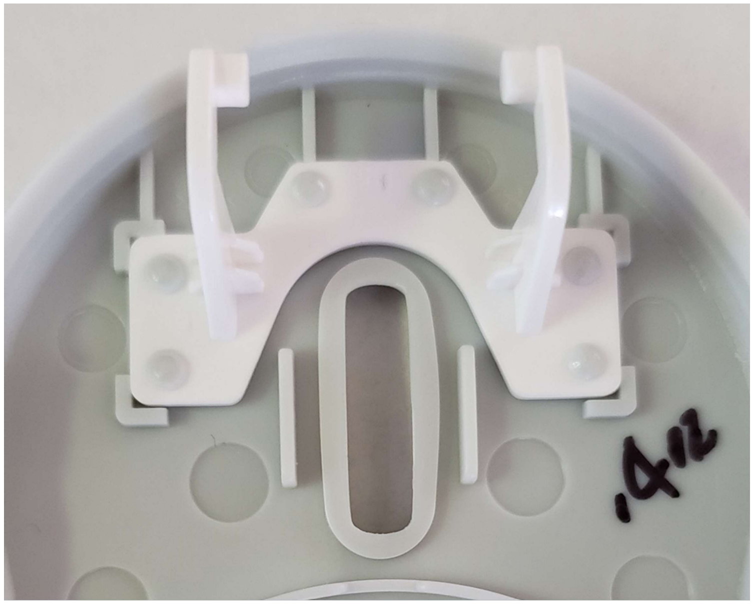
PCB and wiring comparison

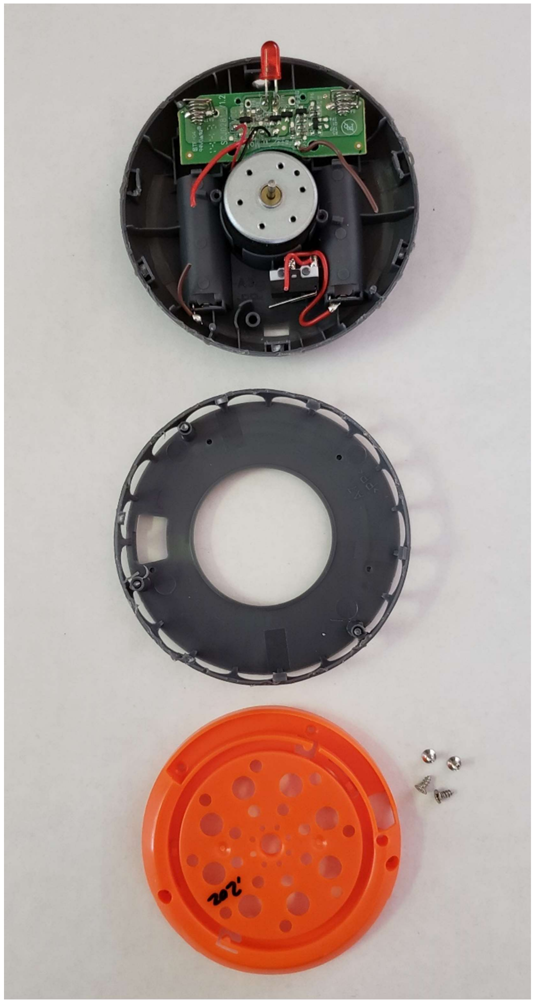
Not sure why the motor isn't in a cup on the 'inside' like the original



DFMA Analysis – What's different

Use of staking



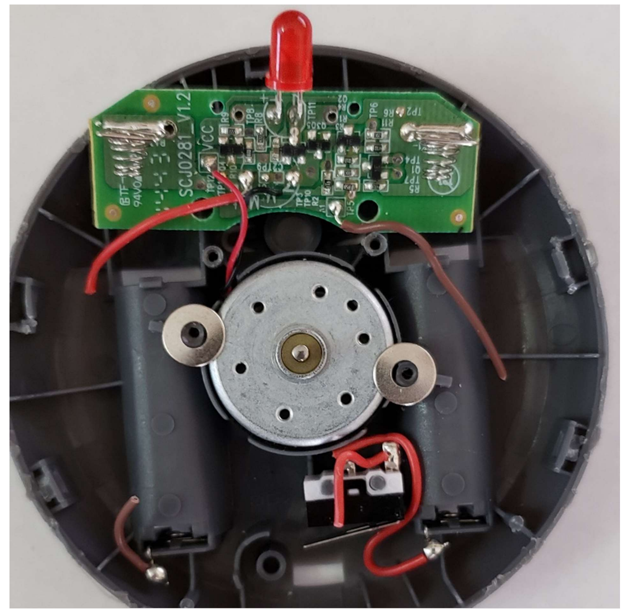


DFMA Analysis – What's different

5 Screws

1 Screw

9 Screws



DFMA Analysis – How did they do?

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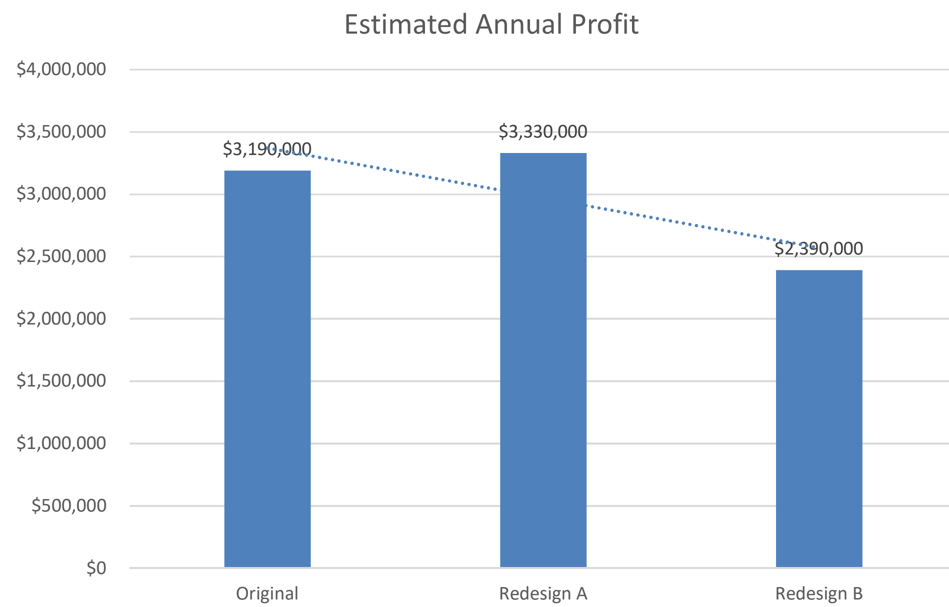
	Mfg Cost	Price	Profit	Annual
Original	$5.75	$8.94	$3.19	$3,190,000
Redesign A	$4.87	$8.20	$3.33	$3,330,000
Redesign B	$5.55	$7.94	$2.39	$2,390,000



What if they used DFMA back in 2008

Based on my study and applying DFA principles the following changes could theoretically be made:

1. Use snap fits to secure all parts
2. Remove PCB and wire to battery connectors like Redesign A
3. Remove LED
4. Motor attached to the 'front side' and held like Original design
5. Since product is round belt clip rotation seems unnecessary
6. 'Orange media disc' seem to have no function other than cosmetic so remove it
7. Maintain same packaging as Redesign B

DFA Analysis Comparison

Entries including repeats	Original	Redesign A	Redesign B	Redesign NPD
Parts meet minimum part criteria	11	11	11	11
Parts are candidates for elimination	13	7	20	3
Analyzed subassemblies	3	3	1	0
Separate assembly operations	9	12	19	10
Total entries	36	33	51	24

Assembly labor time, s				
Parts meet minimum part criteria	60.44	69.53	65.92	69.69
Parts are candidates for elimination	92.69	46.20	153.90	28.07
Insertion of analyzed subassemblies	27.26	32.73	3.54	0
Separate assembly operations	60.75	69.29	116.31	57.87
Total assembly labor time	241.14	217.75	339.68	155.64

Design efficiency				
DFA Index	16.52	18.29	11.73	25.59

DFMA Analysis Comparison

Per product costs, $	**Original**	**Redesign A**	**Redesign B**	**Redesign NPD**
Assembly process	0.48	0.43	0.67	0.31
Manufacturing piece part	3.70	3.23	3.73	3.03
Total cost without tooling	4.18	3.67	4.40	3.34
Total tooling cost	0.10	0.09	0.07	0.06
Total cost	4.28	3.76	4.47	3.40
Total tooling investment, $				
Assembly tools and fixtures	0	0	0	0
Manufacturing tooling	101,101	91,026	74,787	64,555
Total investment	101,101	91,026	74,787	64,555
Production life data and weight				
Life volume	1,000,000	1,000,000	1,000,000	1,000,000
Total production life cost, $	4,278,624	3,756,731	4,473,815	3,401,464
Total weight, lb	0.17	0.13	0.07	0.06




DFMA Analysis – Total Cost Comparison

	Cost per part, $								
	Life volume	Material	Setup	Process	Rejects	Piece part	Tooling	Total	Initial tooling investment
Original Assembly fabrication Polypropylene	1,000,000	4.6125	0.0003	1.0303	0.0021	5.6451	0.1058	5.7510	105,841
Redesign A Assembly fabrication Polypropylene	1,000,000	3.9036	0.0003	0.8652	0.0016	4.7708	0.0959	4.8667	95,904
Redesign B Assembly fabrication Polypropylene	1,000,000	4.3847	0.0003	1.0796	0.0011	5.4657	0.0794	5.5450	79,361
Redesign NPD Assembly fabrication Polypropylene	1,000,000	3.7477	0.0003	0.6675	0.0011	4.4166	0.0691	4.4857	69,129

Boothroyd Dewhurst, Inc.

DFMA Analysis – Total Cost Comparison

	Cost per part, $								
	Life volume	Material	Setup	Process	Rejects	Piece part	Tooling	Total	Initial tooling investment
Original Assembly fabrication Polypropylene	1,000,000	4.6125	0.0003	1.0303	0.0021	5.6451	0.1058	5.7510	105,841
Redesign NPD Assembly fabrication Polypropylene	1,000,000	3.7477	0.0003	0.6675	0.0011	4.4166	0.0691	4.4857	69,129

A difference of $1.2653 or 28.2% of $12,653,000 since 2008 with no design changes

DFMA Analysis – Comments & Conclusions

- You can do this too with your own products
- You have to do the work to gain the knowledge and understanding
- Adding the LED caused issues with this product and demonstrates a lack of understanding of their manufacturing costs (maybe)
- How often does added complexity result, as it did here, with a simple marketing request to add a simple feature.
- How many companies actually understand the cost of added features
- Observe and document during your analysis process
- Question everything and learn for future product development