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UNIVERSIDAD PONTIFICIA

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GRADO EN INGENIERÍA TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

RE-DESIGN FOR MANUFACTURABILITY OF AN ELECTRIC HAND BLENDER

Autor: Ignacio Manrique López-Henares

Director: Leon Liebenberg

Madrid

Mayo de 2019

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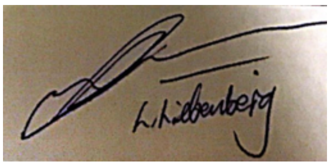

GRADO EN INGENIERÍA TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

RE-DESIGN FOR MANUFACTURABILITY OF AN ELECTRIC HAND BLENDER

Autor: Ignacio Manrique López-Henares

Director: Leon Liebenberg

Madrid

Mayo de 2019

RE-DISEÑO PARA LA MANUFACTURA Y ENSAMBLAJE DE UNA BATIDORA DE COCINA

Autor: Manrique López-Henares, Ignacio

Director: Liebenberg, Leon

Entidad colaboradora: University of Illinois at Urbana-Champaign

RESUMEN DEL PROYECTO

INTRODUCCIÓN

Hoy en día, la mayoría de productos son producidos tras una muy detallada y compleja búsqueda de la mejor manera de manufacturarlos y producirlos con el objetivo de conseguir los estándares mas altos posibles de coste, función y calidad. Esta búsqueda la suelen llevar a cabo un muy amplio equipo de expertos en numerosos campos. En muchas ocasiones con robustos presupuestos económicos y pioneros recursos. El objetivo de este proyecto es intentar la mejora de un producto existente a través de un rediseño para la manufactura en coste, función y calidad con el conocimiento de un estudiante de ingenería industrial y con una serie de recursos ofrecidos por la universidad de Illinois en Urbana-Champaign.

El proyecto estará basado en llevar a cabo el referido rediseño de forma detallada. Nuestro objetivo último será obtener un producto capaz de mejorar su cuota de mercado y de ventas gracias a sus mejores cualidades en función, coste y calidad.

METODOLOGÍA

El proyecto comenzará con el desensamblaje del producto y la construcción de una tabla de componentes donde las diferentes partes del producto estarán reflejadas. A continuación habrá un análisis técnico del producto y un estudio de mercado de los principales competidores que operan en el mismo mercado que el producto elegido.

El primer paso fundamental para conseguir los objetivos es una matriz QFD. Es una metodología enfocada en escuchar la voz del cliente para *a posteriori* responder de forma efectiva a sus necesidades y expectativas. Los dos principales componentes son filas (requerimientos del cliente) y columnas (requerimientos de diseño). La idea es crear relaciones entre ellos, estableciendo un orden de prioridad en las filas, y una dificultad de consecución a las columnas. Con todas estas entradas, la metodología QFD devolverá unas salidas que darán una idea sobre donde concentrar esfuerzos para alcanzar una mayor satisfacción de los clientes.

Al menos un importante componente del producto será rediseñado para mejorar la manufactura o el ensamblaje en el intento de agrandar la cuota de mercado. Al menos 3 ideas de diseño serán

presentadas y con la ayuda de una matriz *Pugh* finalmente se escogerá cual es la mejor idea de diseño para llevar a cabo. El componente rediseñado será después fabricado con un dispositivo de impresión 3-D de la universidad. La impresión 3-D se podría definir como un conjunto de técnicas utilizadas para rápidamente fabricar un modelo a escala de una parte o ensamblaje usando datos de CAD. Hay numerosas ventajas asociadas (así como limitaciones) con esta técnica comparada con otros procesos mas tradicionales como el fresado.

En impresión 3D, la maquina lee *data* de un dibujo de CAD, y deposita sucesivamente capas de material líquido, y de esta manera construye el modelo. Las capas son fusionadas automáticamente para crear la forma final. La ventaja principal de esta forma de construcción "aditiva" es su capacidad para crear prácticamente cualquier geometría.

Los pasos finales del proyecto serán llevar a cabo un análisis del coste de manufactura de nuestra nueva pieza con la ayuda del software *Apriori,* un rudimentario diseño de experimento para testear nuestro producto, y finalmente hacer una comparativa de nuestro nuevo producto con el inicial.

RESULTADOS

Utilizando la matriz QFD y el análisis DFA (Diseño de Ensamblaje), el éxito en el uso del producto y su durabilidad salieron como los puntos en los que concentrar el esfuerzo de rediseño. Y en este contexto, se idearon 3 principales posibles conceptos nuevos de diseño:

- Extensión del producto. A sabiendas de la importancia de la estabilidad del producto para los clientes, este aspecto se podría intentar resolver con un aumento de la longitud del producto. El objetivo de este nuevo diseño sería hacerlo mas ergonómico para usarlo con dos manos, obteniendo un grado mas alto de la referida estabilidad. Además, esto podría abrir la posibilidad de instalar una batería recargable gracias a un aumento del espacio en el interior del producto.

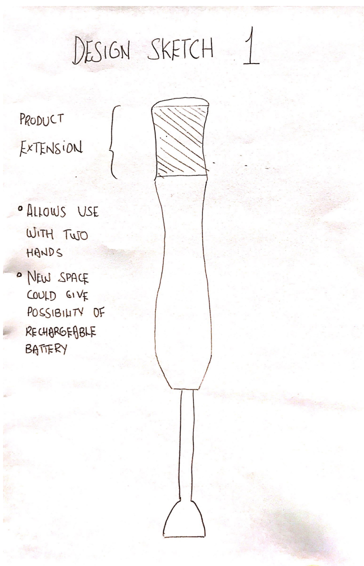

Figura XXVI. Diseño 1

- Cuchillas intercambiables. Mecanismo simple que permitiría intercambiar una cuchilla desgastada por una nueva, afilada.

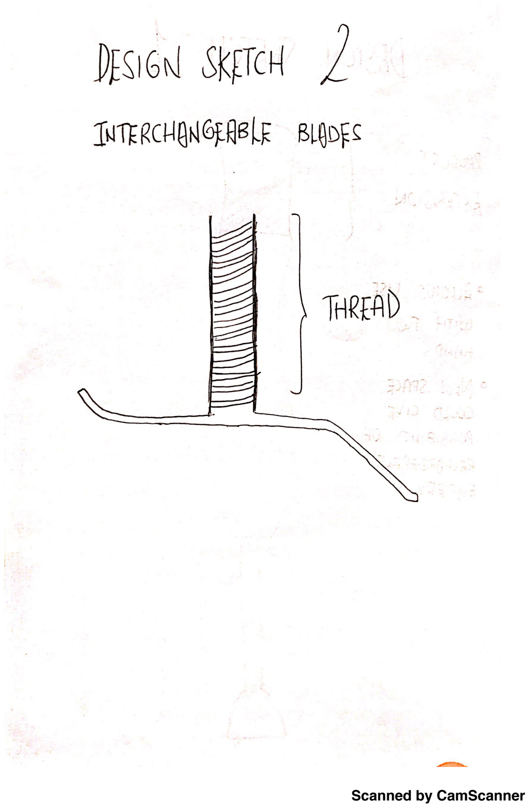

Figura XXVII. Diseño 2

- Tapa de seguridad. Tapa que cubre la parte de la cuchilla con el objetivo de hacerla mas segura en una casa con niños pequeños que podrían utilizarla sin ser consciente del peligro de usarla.

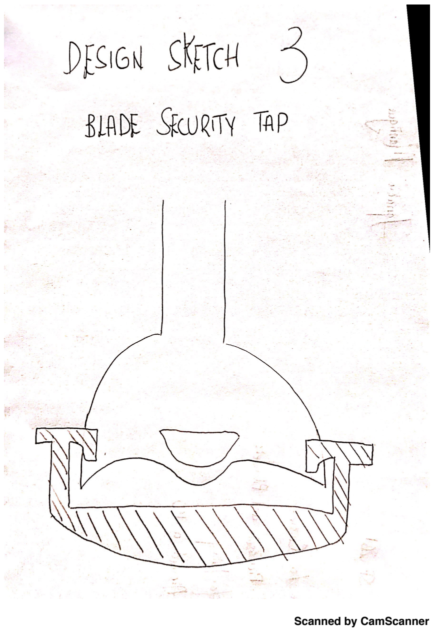

Figura XXVIII. Diseño 3

Utilizando una matriz *Pugh,* se analizaron los 3 nuevos conceptos de diseño en comparación con el producto original para escoger que concepto llevar a cabo.

PUGH MATRIX				DESIGN CONCEPTS		
CUSTOMER REQUIREMENTS	RELATIVE WEIGHT	CUSTOMER IMPORTANCE	ORIGINAL DESIGN	1	2	3
CLEANABLE	9%	4	0	0	-1	-1
AESTHETICS	16%	7	0	1	0	2
ERGONOMIC	12%	5	0	3	0	0
IMPACT	9%	4	0	0	0	1
STABILITY	12%	5	0	3	1	0
BLENDING SUCCESS	19%	8	0	1	3	0
SECURITY	23%	10	0	0	0	3
		43		45	25	47

Figura XXIX. Pugh Matrix

En observación de la matriz *Pugh,* hemos convergido finalmente a una solución final de diseño (tapa de seguridad) al haber obtenido la puntuación mas alta.

CONCLUSIÓN

Figura XLVI. Producto original

Figura XLVII. Producto nuevo

Nuestro re-diseño se ha centrado en una mejora de las características del producto, con un nuevo componente que podría resultar muy atractivo para el nicho de mercado que compra este tipo de productos mas a menudo. En cuanto al coste, el software *Apriori* nos ha estimado un coste extra de $0.46 por unidad que podría ser sumado al precio final del producto para no afectar a los márgenes de rentabilidad de la empresa. Sin embargo, si se pone en la balanza la mejora del producto con su pequeño aumento en el precio, se constataría que llevar a cabo estos cambios en el producto llevaría a una expansión de la cuota de mercado.

RE-DESIGN FOR MANUFACTURABILITY OF AN ELECTRIC HAND BLENDER

Author: Manrique López-Henares, Ignacio

Director: Liebenberg, Leon

Collaborative institution: University of Illinois at Urbana-Champaign

INTRODUCTION

Most of today´s products are produced after a very detailed and complex research of how to produce them in pursuit of gaining the highest scores possible of function, cost and quality. This research is conducted by a broad range of experts in very numerous fields and in many occasions with vast budgets that allow them to use the best and most up-to-date resources. The objective of this project is to endeavour to improve an existing product through a re-design for manufacturability in cost, function and quality with the knowledge of an engineering student and a few resources provided by the university.

The project will be based on performing a detailed re-design for manufacturability of an electric hand blender. Our ultimate intent in this project is to improve the market share of the product via an improvement of function, cost or quality.

METHODOLOGY

The project will commence by disassembling the product and constructing a Bill of Materials where all the different parts that make the product will be reflected. This will be followed by an analysis of the technical specifications of the product and a market research of the main competitors operating in the same market of my chosen product.

The first cornerstone our intent to achieve our objectives is a QFD matrix. It is a focused methodology to carefully listen to the voice of the customer and then effectively responding to those needs and expectations. The two main components are rows (customer requirements) and columns (design requirements). The idea is to create relations between them, establishing an order of priority with regard to the customer requirements, whilst giving a difficulty of accomplishment to the design requirements. With all your inputs, the QFD methodology will provide you some output ratings about the best areas to concentrate on to achieve the highest customer satisfaction.

At least one important component or sub-assembly in this product will be redesigned to make for improved manufacturing and assembly in pursuit of gaining improved market share. At least 3 design ideas will be presented and with the help of a Pugh matrix we will finally choose one to go forward in the last stages of the product. The redesigned component/s must then be fabricated in the Innovation Studio of the university with a 3-D printing device. 3D Printing can be defined as a group of techniques utilised to quickly fabricate a scale model of a part or assembly using CAD data. There are several benefits (as well as limitations) with these techniques as compared to more traditional subtractive processes, such as milling or turning.

In 3D Printing, the machine reads in data from a CAD drawing, and lays down successive layers of liquid or powdered material, and in this way builds up the model from a series of cross sections. These layers, are glued together or fused (sometimes using a laser) automatically to create the final shape. The primary advantage to this type of 'additive' construction is its capacity to create almost any geometry.

The last stages of the project will be to conduct a manufacturing cost analysis with the help of the software *Apriori*, a rudimentary design of experiment method to test our product, and finally mull over our final product compared to the one we began with.

RESULTS

Leveraging the QFD analysis of the customer requirements and competitor products, and the DFMA analyses, we found blending success and lifespan as points to concentrate our effort on. And in this context, I have brainstormed 3 main ideas of design:

- Product extension. Acknowledging stability as an important customer requirement, the aspect could be addressed with an augmentation of the length of the superior and inferior outer bodies. The ultimate objective would be to make it ergonomic to use with both hands, achieving a higher grade of the aforementioned stability. Furthermore, this could open the possibility of installing a rechargeable battery thanks to an increase of the space available inside the bodywork.

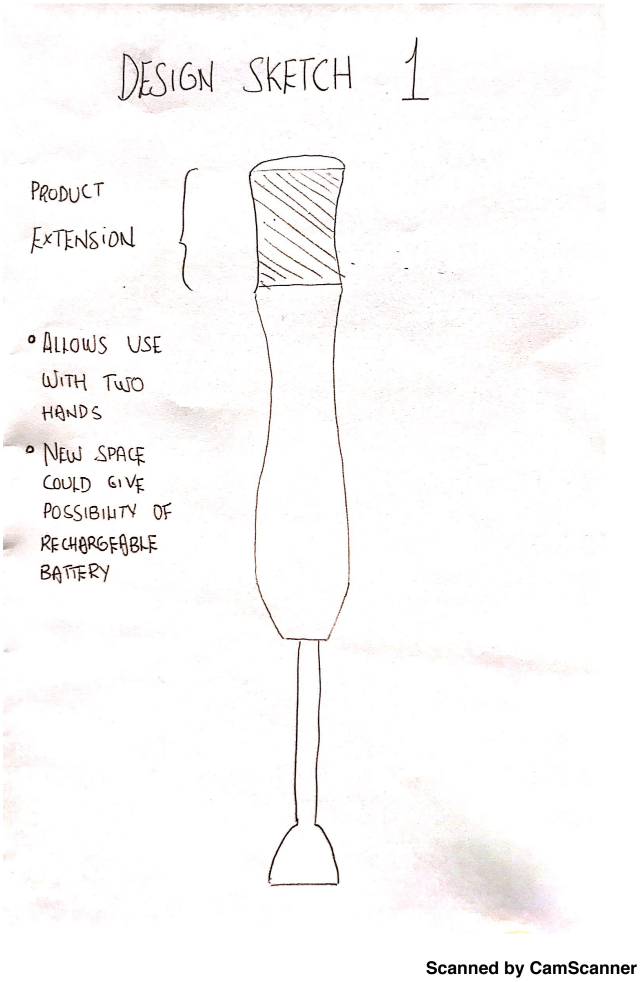

Figure XXVI. Design sketch 1

- Interchangeable blades. Simple mechanism that allows the blade to be removed and put on a new, sharper one.

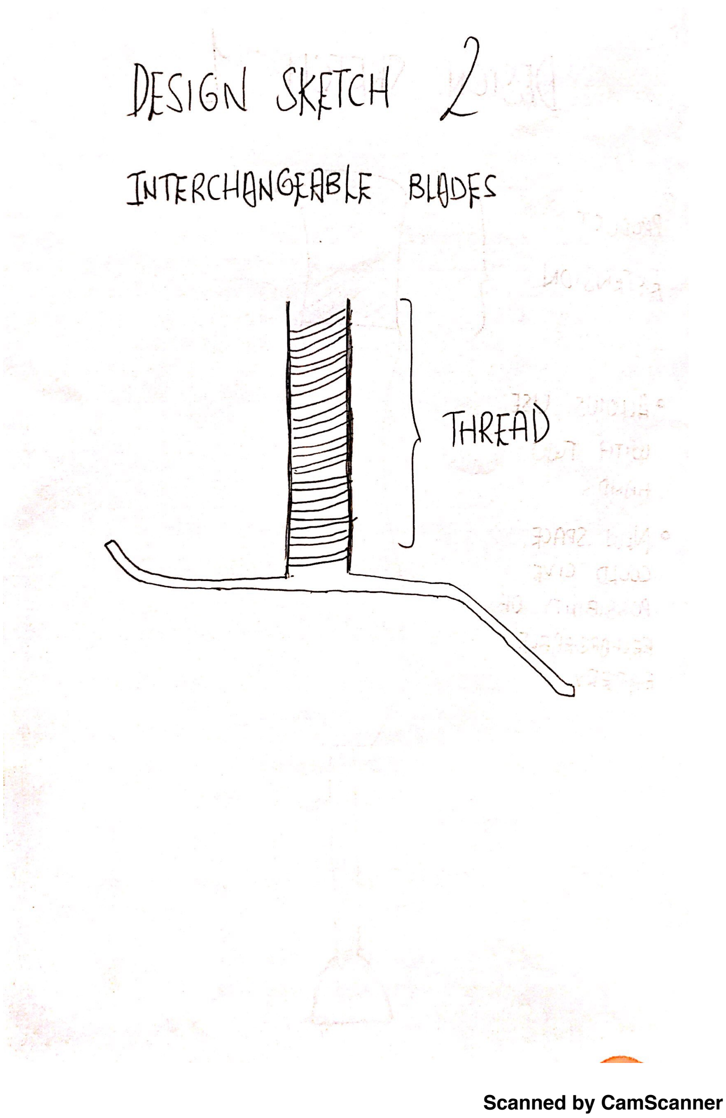

Figure XXVII. Design sketch 2

- Blade security tap. Tap that covers the blade part of the product in pursuit of making it safer in a household with little children that could use it without realizing it´s danger.

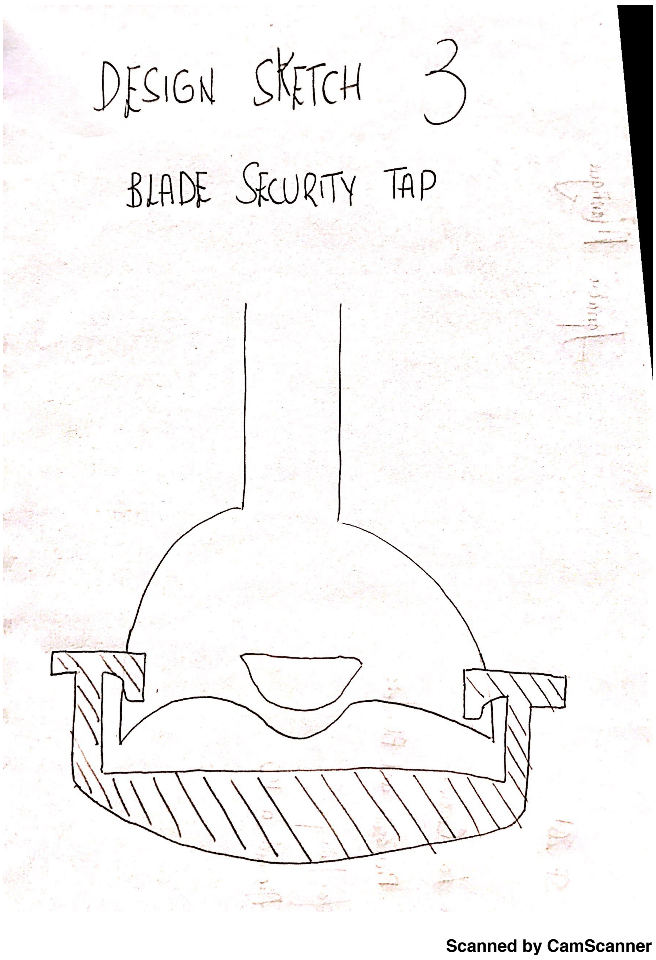

Figure XXVIII. Design sketch 3

Using a Pugh Design matrix we analyzed and ranked each of the three design sketches in comparison to the original product to help narrow down an idea for our final prototype.

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		43		45	25	47

Figure XXIX. Pugh Matrix

In observation of the Pugh Matrix, we have finally converged to a final design solution (blade security tap) as it scored the highest punctuation in accordance to the customer requirements.

CONCLUSION

Figure XLVI. Original product

Figure XLVII. Re-designed product

Our re-design has ultimately focused on an improvement of function, with a new feature that could result very attractive to the niche market that buys this kind of products more often. With regards to cost, the *Apriori* output has given an extra cost of $0.46 to the product that could be added to the ending retail price in pursuit of not damaging margins. However, if we put in the balance the improvement of our product and its little increase in price, I believe the result will be an increase of market share, which is the ultimate objective.

Index

INTRODUCTION

The project will be based on performing a detailed re-design for manufacturability of an electric hand blender. The project will commence by disassembling the product and constructing a Bill of Materials where all the different parts that make the product will be reflected. This will be followed by an analysis of the technical specifications of the product and a market research of the main competitors operating in the same market of my chosen product.

Our ultimate intent in this project is to improve market share via an improvement of function, cost or quality. And in this context, the first cornerstone is a QFD matrix. It is a focused methodology to carefully listen to the voice of the customer and then effectively responding to those needs and expectations. The two main components are rows (customer requirements) and columns (design requirements). The idea is to create relations between them, establishing an order of priority with regard to the customer requirements, whilst giving a difficulty of accomplishment to the design requirements. With all your inputs, the QFD methodology will provide you some output ratings about the best areas to concentrate on to achieve the highest customer satisfaction.

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The last stages of the project will be to conduct a manufacturing cost analysis with the help of the software *Apriori*, a rudimentary design of experiment method to test our product, and finally mull over our final product compared to the one we began with.

MANUFACTURING TECHNIQUE

The manufacturing technique that we will be using for the purpose of this project is 3D Printing. 3D Printing can be defined as a group of techniques utilised to quickly fabricate a scale model of a part or assembly using CAD data. There are several benefits (as well as limitations) with these techniques as compared to more traditional subtractive processes, such as milling or turning.

In 3D Printing, the machine reads in data from a CAD drawing, and lays down successive layers of liquid or powdered material, and in this way builds up the model from a series of cross sections. These layers, are glued together or fused (sometimes using a laser) automatically to create the final shape. The primary advantage to this type of 'additive' construction is its capacity to create almost any geometry.

Construction of a part using 3D Printing machines typically takes anywhere from minutes to hundreds of hours, depending on machine and model size. Often this process is used to make prototypes since design changes are quick and easy, and sometimes used in limited production when many parts are built in parallel.

In manufacturing, it is important to guide a product from concept to market quickly and inexpensively. 3D Printing helps in that process. It automates the fabrication of a prototype part from a three-dimensional (3D) CAD drawing. This physical model can collect more complete information about the product, and earlier in the development cycle. 3D Printing can be a quicker, more cost-effective means of building prototypes in comparison to other methods.

3D Printing technologies are exclusively additive processes. Starting material can be liquid, as in a photocurable liquid, solid, as in a meltable thermoplastic material, or powder. Photo-polymer systems start with a liquid resin, which is then solidified by exposure to a specific wavelength of light. Thermoplastic systems begin with a solid material, which is then melted and fuses upon cooling. Powder systems use a laser to locally fuse powders together. 3D Printing systems are capable of creating parts with small internal cavities and complex geometries.

OBJECTIVES

Problem statement

Most of today´s products are produced after a very detailed and complex research of how to produce them in pursuit of gaining the highest scores possible of function, cost and quality. This research is conducted by a broad range of experts in very numerous fields and in many occasions with vast budgets that allow them to use the best and most up-to-date resources. The objective of this project is to endeavour to improve an existing product through a re-design for manufacturability in cost, function and quality with the knowledge of an engineering student and a few resources provided by the university.

Market need

In order to know where the product that was going to be analysed sits in the market, a rough industry research was conducted, noting the prices and main specifications of the different competitors. Figure I provides a schematic view of what are the characteristics of our product in comparison to the typical in the market. This could end up playing an important role in identifying pinpoints that could drive our intent of redesigning the product.

	CHARACTERISTICS			
Brands	Watts	Speeds	2 in 1	Retail price
BELLA	250	2	YES	$16,47
Ovente	300	2	NO	$17,81
Americana	150	1	NO	$19,99
Nuovoware	400	6	YES	$19,99
Cuisinart	200	2	NO	$34,99
Betty Crocker	200	2	NO	$15,86
Hamilton Beach	225	2	NO	$24,99

Figure I. Competitor landscape

A further investigation of the market landscape was to see some figures of the size of the industry and what were the key drivers of it. This would provide a more solid view to exploit opportunities that the market could offer in our intent to improve market share.

From the IBISWorld industry review I have been able to extract very interesting information of the industry. Even though the industry that is analyzed is broader than ours, key industry drivers and other elements are definitely very strongly related. The industry is “Food Processor and Blender Manufacturing in the US”.

Key external drivers:

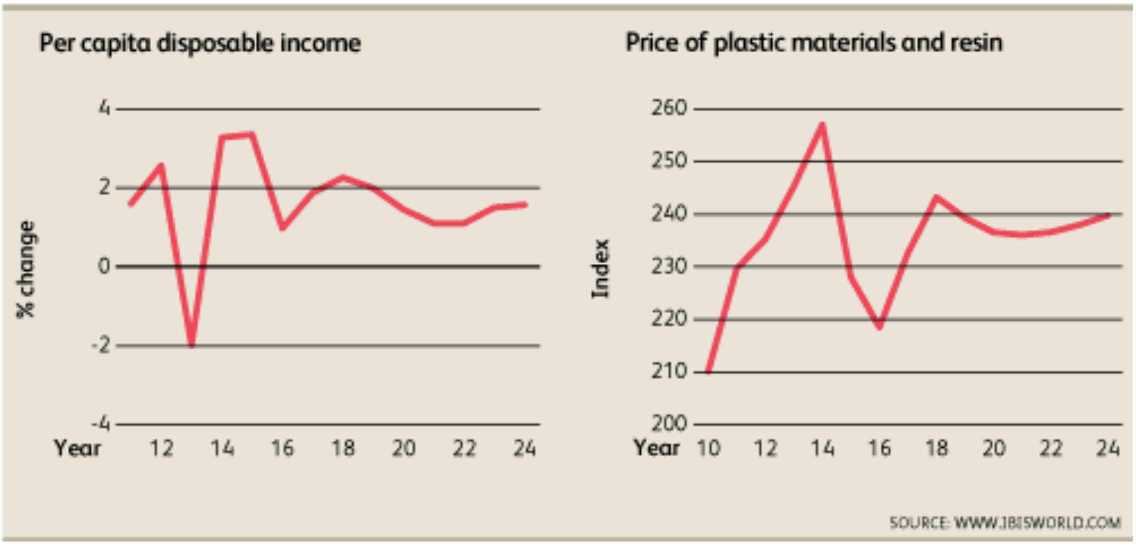


Figure II. US per capita disposable income and price of plastic materials

- **Import penetration into the manufacturing sector.** The manufacturing of many low-tech products is increasingly being outsourced to countries with low wage costs. Domestic manufacturers typically cannot compete with these foreign manufacturers on price, which forms the basis of competition for most low-tech products including food processors and blenders.
- **Per capita disposable income.** Since industry goods are discretionary purchase, a rise in per capita disposable income increases the propensity for customers to purchase more expensive, higher-quality industry products. As a result, rising per capita disposable income is beneficial to the industry. However, for our specific product, who lies in the lower end of the market, this could actually represent a threat more than an opportunity.
- **Price of plastic materials and resin.** Plastic materials and resin are among the most important inputs in the manufacturing of blenders. As a result, growth in the price of these materials tends to raise industry purchases costs. If these costs cannot be fully passed on to downstream customers, industry profit suffers. The price of plastic materials and resin is expected to increase in 2019, posing a potential threat to the industry.

Project goals

The main goal of our project is to achieve improved market share with better results in terms of function, cost and quality. And to attain this, we have other parallel or more concrete goals:

- Conduct an industry research to know what the landscape is in terms of prices and the lower and higher ends of the market.
- Brainstorm customer requirements and quantifiable design requirements to meet the customer requirements.
- Construction of a QFD matrix as a helpful tool to know where to concentrate our efforts of design.
- Perform a DFA analysis to mull over any opportunities to combine or eliminate parts that exist in our product.
- Think of new design ideas and ultimately choose one with the use of a Pugh matrix.
- Design with CAD our prototype in order to print it with a 3-D printing device.
- Test our prototype and compare our new one with the initial one to extract some final conclusions.

PRODUCT ANALYSIS

Bill of Materials

Figure III. Product picture

The following set of pictures reflect the different parts I found after the product´s disassembly. Each part will have a part number as identification (in between parentheses) to clarify to which part I am referring to in the Bill of Materials created in Excel. Following the Bill of Materials, will be a hand-drawn sketch showing an exploded view of the product.

Figure IV. Top cap (I)

Figure V. Supporting ring (II)

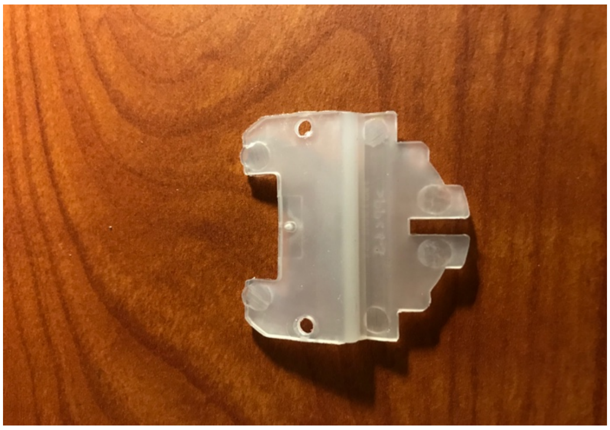


Figure VI. Supporting platform (III)

Figure VII. Motor stability support (IV)

Figure VIII. Superior outer body (V)

Figure IX. Inferior outer body (VI)

Figure X. Screws (VII)

Figure XI. Motor (VIII)

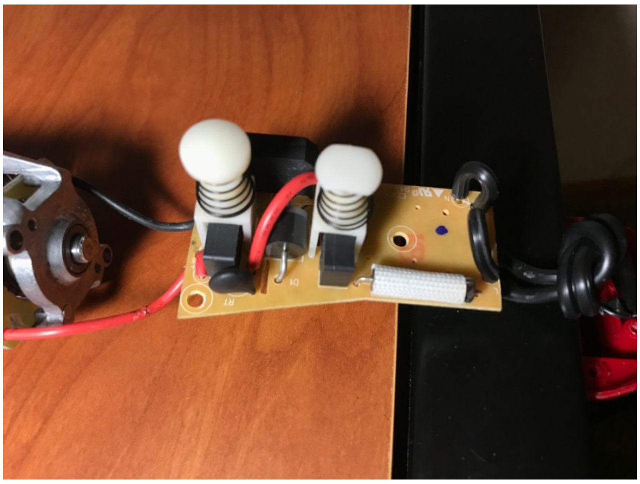


Figure XII. Control circuit board (IX)

Figure XIII. Shaft (X)

Part No.	Part name	Quantity	Material	Manufacturing process
1	Top cap	1	ABS	Plastic injection molding
2	Supporting ring	1	ABS	Plastic injection molding
3	Supporting platform	1	PP	Polymerization of propylene gas
4	Motor stability support	2	Rubber	Compounding, mixing, shaping and vulcanizing
5	Superior outer body	1	ABS	Plastic injection molding
6	Inferior outer body	1	ABS	Plastic injection molding
7	Screws	10	Stainless steel	Thread-rolling
8	250 Watt motor	1	-	Purchased
9	Control circuit board	1	-	Purchased
10	Shaft	1	ABS and stainless steel	Plastic injection molding and metal casting

Figure XIV. Bill of materials

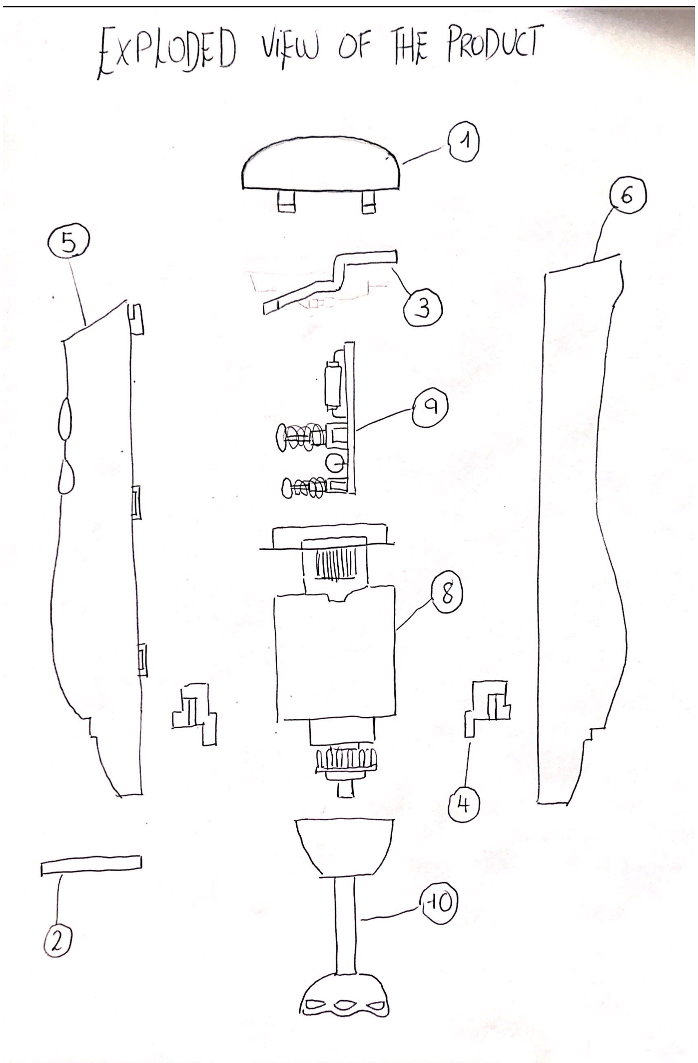


Figure XV. Exploded view of the product

Product Design Specification (PDS)

I. **Performance.**
- Give possibility of changing blades when they turn blunt
- Provide security to households where there is little children

II. **Environment**
- Noise levels: N/A
- Insects: N/A
- Vibration: N/A
- Supports all humidity conditions
- The temperature should be standard living conditions
- Should not be corroded by precipitation, but could be dangerous to use if wet

III. **Service Life**
- Being service life one of the main customer requirements and taking into account that one of our improvements will be driven by it, we estimate 15 years as a reasonable service life for this product.

IV. **Maintenance**
- Interchangeable blades can be bought separately.
- Regular maintenance for other issues not desired.
- Brings warranty

V. **Target Cost**
- Retail cost: $16
- Cost of Goods Sold (COGS): $7

VI. **Competition**
- We pursue a cost leadership strategy
- By having analyzed the online market possibilities, we know our product lies in the lower end of the market

VII. **Shipping**
- Ground, sea or air to ship domestically and overseas
- Dry van trucks to protect our product from rain when on ground

VIII. **Product Volume**
- Practically every household needs this product, thus big market
- The Volume depends a lot on the company´s revenues and distribution channels, which are confidential

IX. **Packaging**
- The product comes inside a plastic protection that comes inside a rectangular cardboard box

X. **Manufacturing facilities**
- The new design would not need any extra manufacturing facilities

XI. **Size**
- Our security tap could extend the length of our product in a small percentage

XII. **Weight**

- The product´s weight is 1140 grams

XIII. **Aesthetics**

- The product is only sold in one color, red
- The design is moderate as the kitchen design trends are nowadays and is therefore aesthetically appealing

XIV. **Materials**

- The new parts, security tap and changeable blades will be made of the two main materials in the product, ABS and stainless steel

XV. **Product Life Span**

- As previously said, 15 years
- Dependent on impacts and care in its usage

XVI. **Standards, Specifications, and Legal Aspects**

- The new security tap will definitely be a way to protect the company in lawsuits regarding accidents occurred

XVII. **Ergonomics**

- Follows the ergonomics of a human hand, and is designed with that objective

XVIII. **Customer**

- Anyone interested in home-made food or more elaborated recipes

XIX. **Quality and Reliability**

- While the defects per unit are unknown to us, we can assume that the number is low

XX. **Shelf life**

- Made of metal and plastic
- The metal should be resistant to rust
- Little decay expected
- +20 years

XXI. **Manufacturing processes**

- Injection molding for the plastics
- Metal casting

XXII. **Timescales**

- PDS, QFD matrix, Direction of Improvement matrix, and DFMA analysis
    - Due 5 April
- CAD model of existing product, APriori analysis of existing product, Pugh matrix, and CAD model of new product
    - Due 16 April
- Product launch (due 30 April)

XXIII. **Testing**

- To test our product, a testing office should be added to the existing plants/factories to ensure the quality of the product

XXIV. **Safety**

- Safety is a concern in our product, but our new product design comes to make it an even safer product in all contexts

XXV. **Company constraints**

- Having followed a cost leadership strategy, the new design product may increase the cost a bit and we may lose our competitive edge with regards to the price

XXVI. **Market constraints**

- The market is highly competitive and thus any move in terms of new features will be closely followed by competitors

XXVII. **Political and Social Implications**

- Our product has no implications on political or social structures

XXVIII. **Disposal**

- We will attempt to use the reuse the waste product from our machines to ensure that the least amount of material is wasted at the end of the day. We will also ask that customers recycle our product if they decide to throw it away.

Design for Process and Design for Assembly analysis of the product

Design for manufacturability involves both design for process and design for assembly.

In the design for process the objective is for the designer to decide on the preferred method by which parts, components, or structural elements will be fabricated, and to take the method(s) into account when deciding details or features.

Our product has two well differentiated parts in its outer bodywork. The dividing line of this two parts is shown below.

Figure XVI. Design for process

Part number 2 is made of steel whilst all of number 1 is made of plastic ABS. The former was manufactured through metal casting most probably whilst the latter through plastic injection molding. Engineers at this stage may have thought that part number 2 needed to be more resistant both to temperatures and impacts, and thus chose steel as the material for it (improvement of function). These characteristics were not needed by part number 1 and so in pursuit of lessening costs, they decided to use plastic as a cheaper material. I also believe that there was some intent in this division of material use of achieving a more aesthetically appealing product.

The design for assembly (DfA) stage pursues to design a product that features ease of assembly of the detail parts. During DfA, we could identify simple criteria to theoretically determine whether any parts in an assembly could be eliminated or combined.

An efficient way of identifying opportunities for simplification by reducing the number of parts is to ask ourselves the following three questions:

-Does a particular part move relative to all other parts in the assembly?

-Must a particular part be made of a different material than other parts in the assembly?

-Must a particular part be separate from other parts in the assembly?

Thus, I have laid out in a table the answers to these these three questions for each part. I have thought that if the answer to the three questions was no, then it would be a potential candidate for elimination or combination. With regards to the motor and the control circuit board I decided they were not applicable to reflect on these questions, as they have to exist for sure in a separate way. See below the table where you can also see that the minimum number of parts is 6, whilst the theoretical number of parts was 10.

			DFA QUESTIONS		
Part No.	**Part name**	**Opportunity to combine or eliminate?**	1	2	3
1	Top cap	Yes	NO	NO	NO
2	Supporting ring	Yes	NO	NO	NO
3	Supporting platform	Yes	NO	NO	NO
4	Motor stability support	Yes	NO	NO	NO
5	Superior outer body	No	NO	NO	YES
6	Inferior outer body	No	NO	NO	YES
7	Screws	No	NO	YES	YES
8	250 Watt motor	No	-	-	-
9	Control circuit board	No	-	-	-
10	Shaft	Yes	NO	NO	NO
		Theoretical number of parts	10		
		Minimum number of parts	6		

Figure XVII. Opportunities to combine or eliminate parts

Reflecting on the opportunities to combine or eliminate, I believe that the supporting ring and motor stability support could be directly eliminated and the product could still function correctly. Whilst the top cap and supporting platform could be combined in some way and thus reduce one part. And the last part that appears to have opportunities to combine or eliminate is the shaft. However, even though it could actually be made out of plastic as it is the case with some other electric hand blenders, I believe it is better to make it of steel in order to provide it a higher resistance to temperature.

Customer Requirements and Quantifiable Design Requirements

Electric hand blender

Average customer: Male/female 30-60 years, Middle class, Wishes to do some more elaborated recipes, has common household kitchen space

Preliminary customer requirements list

i. **Cleanable.** Possibility of introducing it in the dishwasher (should not suffer in the long run by doing this). However, it will also be important for it to be relatively easy to clean by hand, knowing that part of the target customers may not have a dishwasher at their home.
ii. **Aesthetics.** Design normally plays quite an important role in many kitchen appliances and most enterprises endeavor to have elegant and well-finished products. Certain customers are specially strict with this feature.
iii. **Ergonomic.** Should be pleasant to handle with a shape that adapts really well to a human hand.
iv. **Impact.** Having to handle with a few things simultaneously in the kitchen leads to items falling in many occasions. Thus, an impact resistant product will be vital for the customer´s loyalty. A break derived from an impact may most probably result in the loss of a customer.
v. **Stability.** When using the blender, certain weight in the product will be important to give it stability. It is true that you do not want it to be either too heavy as that could be uncomfortable. Thus, in this case we should look for the weight that gives it enough stability without making the product too heavy that would make it less easier to use.
vi. **Possibility of changing blades.** Blades will eventually become blunt and therefore having the option of inserting a new blade that will keep the quality of the blade´s slicing and cutting on the long run is definitely an important customer requirement.
vii. **Easy to handle and use.** A comfortable and soft button to make it function will also be an important characteristic.
viii. **Affordable.** Practically all customers will take price into consideration and thus our cost of production will be really important in the price we can offer our customers, in our intent to gain the biggest market share possible.
ix. **Size.** Customers will look for a considerable length of the shaft to make the device useful in deep recipients. However, the target is not to make it as long as possible. A far too long device would make it uncomfortable in terms of fitting drawers.
x. **Low carbon footprint.** A few customers could be concerned with how eco-friendly the product is.

In between all these customer requirements, I have made a selection of the one I believe are most important for the customers and thus the ones that are in the QFD matrix:

- Easy to use
- Affordable
- Stability

- Possibility of changing blades
- Durable

Quantifiable design requirements

- Force to press the ON button (N)
- Weight (g)
- Length (cm)
- Volume (m^3)
- Blending success (%)
- Failure rate over life (%)
- Cost ($)
- Heat limit resistance (ºC)
- Life span (yrs)

Quality Function Deployment matrix (QFD matrix)

Every organization has customers. Some have internal customers, some have only external customers, some have both. When you are working to determine what you need to accomplish to satisfy those customers, an essential tool is quality function deployment or QFD matrix. It is a focused methodology for carefully listening to the voice of the customer and then effectively responding to those needs and expectations.

The two main components are rows (customer requirements) and columns (design requirements). The idea is to create relations between them, establishing an order of priority with regard to the customer requirements, whilst giving a difficulty of accomplishment to the design requirements. With all your inputs, the QFD methodology will provide you some output ratings about the best areas to concentrate on to achieve the highest customer satisfaction.

First of all, I will leave a picture of the legend of the QFD that I have developed.

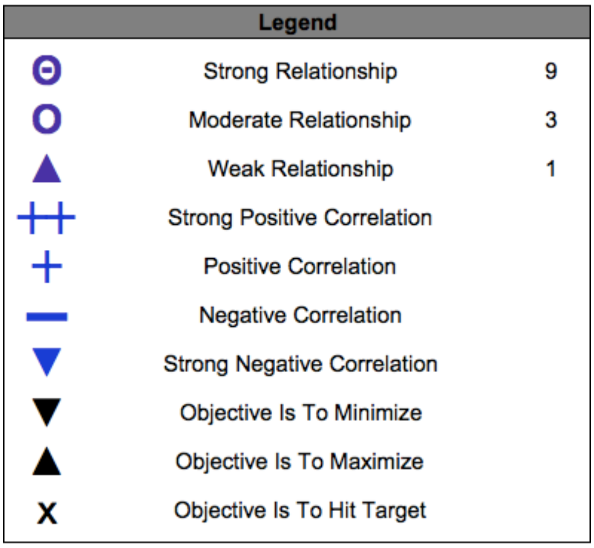
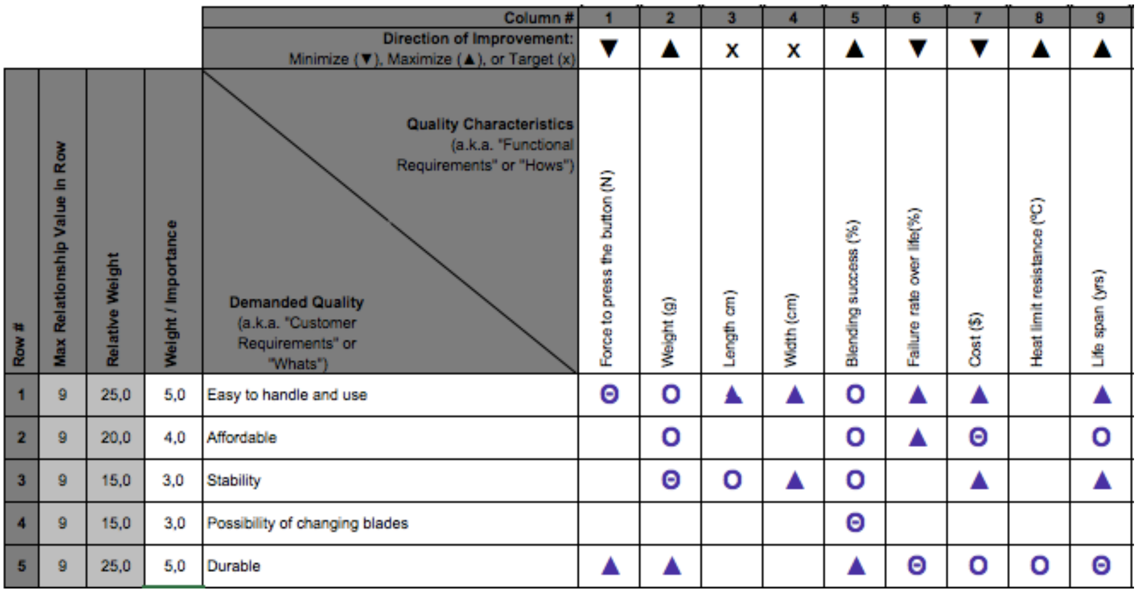


Figure XVIII. QFD legend

On figure XIX, you can see the relations between the chosen main customer requirements and all the suitable design requirements to capture and translate customer requirements into suitable metrics.



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column # / Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x) / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	1 Force to press the button (N)	2 Weight (g)	3 Length cm)	4 Width (cm)	5 Blending success (%)	6 Failure rate over life(%)	7 Cost ($)	8 Heat limit resistance (ºC)	9 Life span (yrs)
					▼	▲	x	x	▲	▼	▼	▲	▲
1	9	25,0	5,0	Easy to handle and use	Θ	O	▲	▲	O	▲	▲		▲
2	9	20,0	4,0	Affordable		O			O	▲	Θ		O
3	9	15,0	3,0	Stability		Θ	O	▲	O		▲		▲
4	9	15,0	3,0	Possibility of changing blades					Θ				
5	9	25,0	5,0	Durable	▲	▲			▲	Θ	O	O	Θ

Figure XIX. QFD picture 1

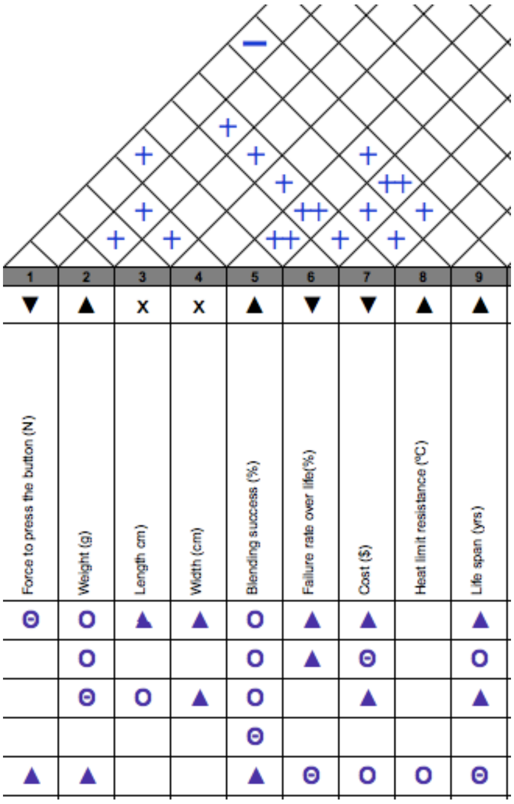


Figure XX. QFD picture II

In Figure XX the relations between the design requirements are shown. And in Figure XXI, it is where we can observe the outputs.

Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Force to press the button (N)	Weight (g)	Length cm)	Width (cm)	Blending success (%)	Failure rate over life(%)	Cost ($)	Heat limit resistance (ºC)	Life span (yrs)
Easy to handle and use	Θ	O	▲	▲	O	▲	▲		▲
Affordable		O			O	▲	Θ		O
Stability		Θ	O	▲	O		▲		▲
Possibility of changing blades					Θ				
Durable	▲	▲			▲	Θ	O	O	Θ
Target or Limit Value	0.5	1140	38	6	90	0.1	8	65	15
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	1	3	2	2	4	4	5	4	5
Max Relationship Value in Column	9	9	3	1	9	9	9	3	9
Weight / Importance	250,0	295,0	70,0	40,0	340,0	270,0	295,0	75,0	325,0
Relative Weight	12,8	15,1	3,6	2,0	17,3	13,8	15,1	3,8	16,6

Figure XXI. QFD picture III

In observation of figure XXI, we can conclude that the design requirements with the highest relative weight are, in order, blending success (%), lifespan (years) and cost ($).

Competitive Analysis
(0=Worst, 5=Best)

Our Company	Betty Crocker	Hamilton Beach	Nuovoware		
4	5	5	3		
4	3	2	3		
3	5	4	5		
0	0	0	0		
3	4	5	4		

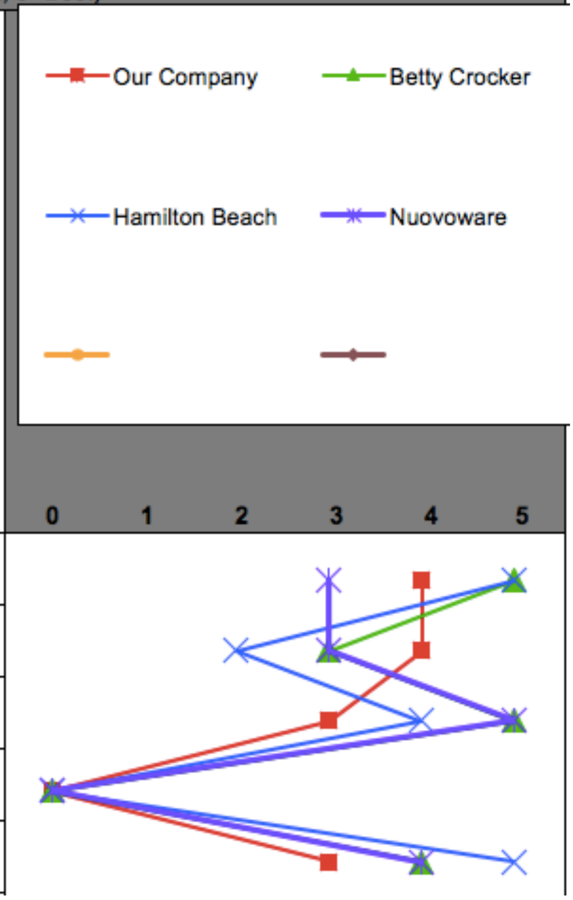


Figure XXII. Competitive analysis in QFD

I also elaborated a competitive analysis with our main competitors as it is also an important part of the QFD (figure XXII).

CAD Modelling of the existing product

Our main part under investigation is the shaft of our whole hand blender. Below are CAD screenshots of it.

Figure XXIII. Side view

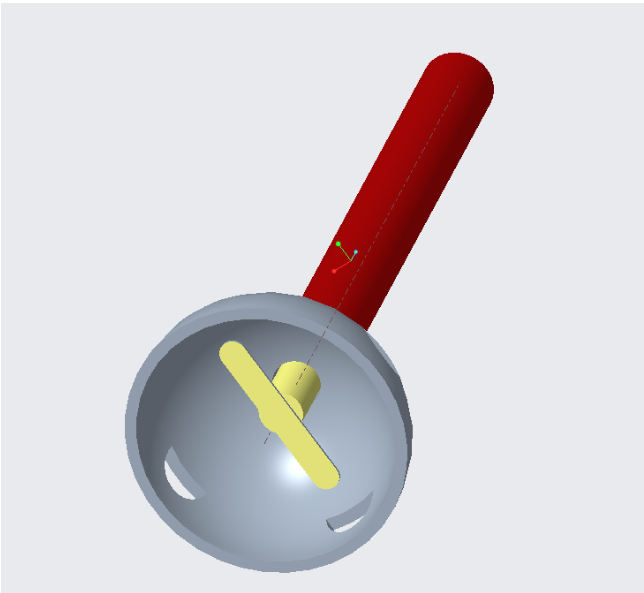


Figure XXIV. Bottom view

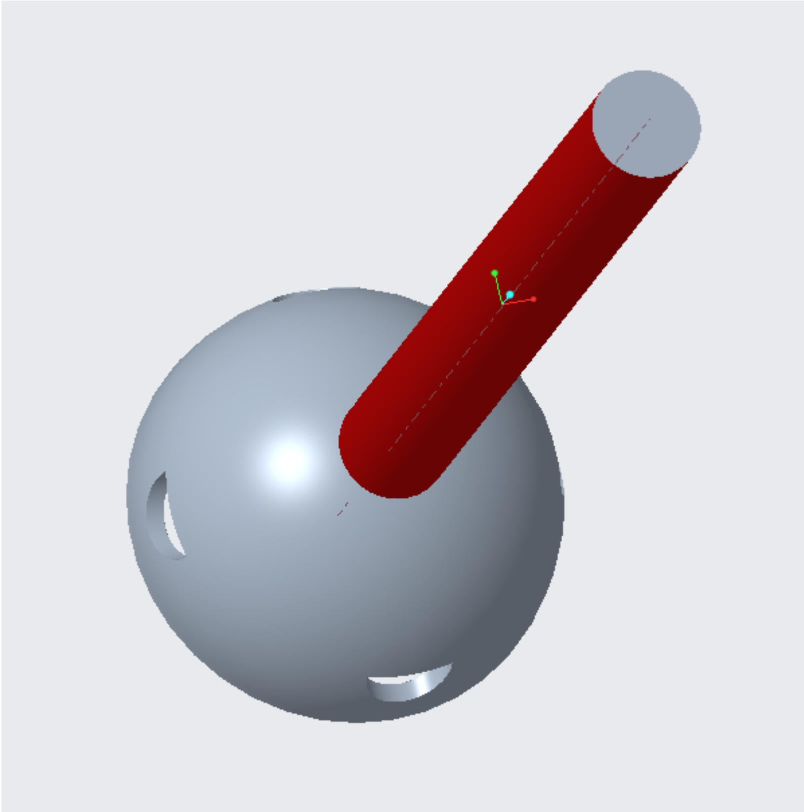


Figure XXV. Top view

DESIGN IDEATION AND EXECUTION

Design ideas

Leveraging the QFD analysis of the customer requirements and competitor products, and the DFMA analyses, we found blending success and lifespan as points to concentrate our effort on. And in this context, I have brainstormed 3 main ideas of design:

- Product extension. Acknowledging stability as an important customer requirement, the aspect could be addressed with an augmentation of the length of the superior and inferior outer bodies. The ultimate objective would be to make it ergonomic to use with both hands, achieving a higher grade of the aforementioned stability. Furthermore, this could open the possibility of installing a rechargeable battery thanks to an increase of the space available inside the bodywork.

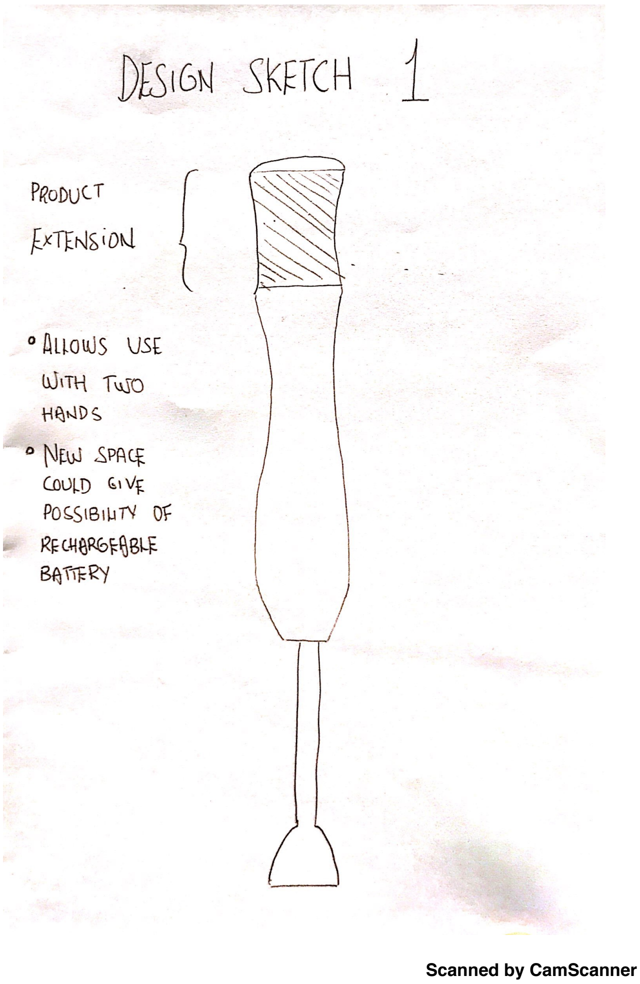


Figure XXVI. Design sketch 1

- Interchangeable blades. Simple mechanism that allows the blade to be removed and put on a new, sharper one.

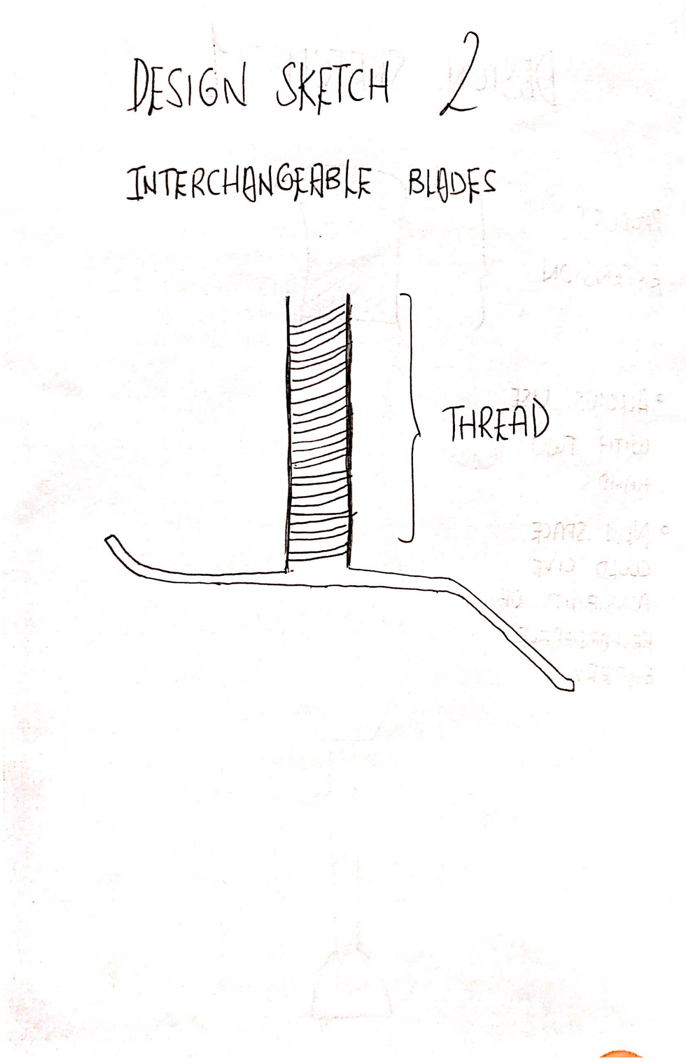


Figure XXVII. Design sketch 2

- Blade security tap. Tap that covers the blade part of the product in pursuit of making it safer in a household with little children that could use it without realizing it´s danger.

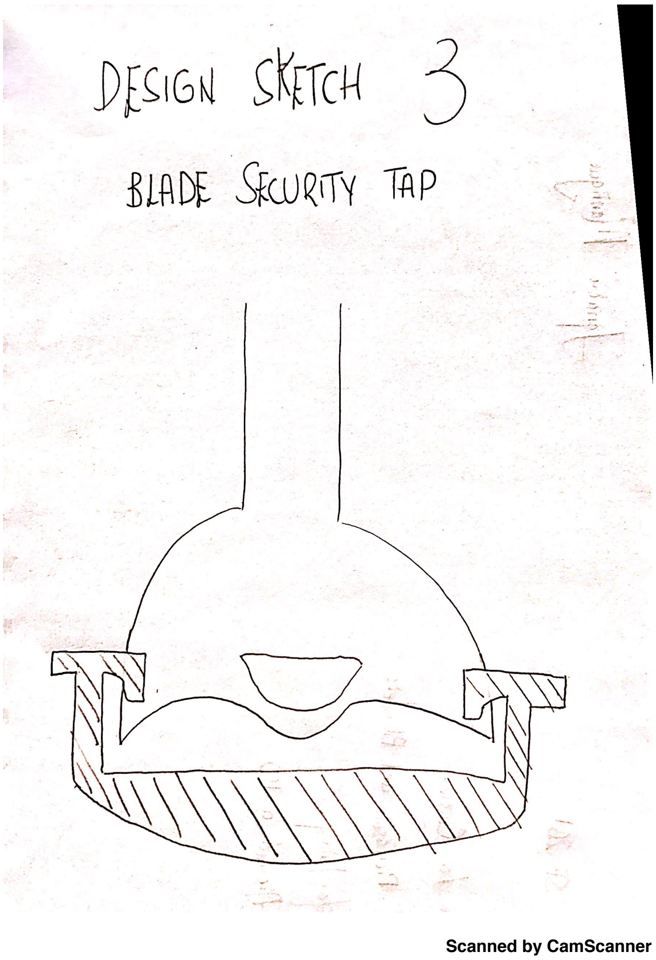


Figure XXVIII. Design sketch 3

Design decision

Using a Pugh Design matrix we analyzed and ranked each of the three design sketches in comparison to the original product to help narrow down an idea for our final prototype.

PUGH MATRIX				DESIGN CONCEPTS		
CUSTOMER REQUIREMENTS	RELATIVE WEIGHT	CUSTOMER IMPORTANCE	ORIGINAL DESIGN	1	2	3
CLEANABLE	9%	4	0	0	-1	-1
AESTHETICS	16%	7	0	1	0	2
ERGONOMIC	12%	5	0	3	0	0
IMPACT	9%	4	0	0	0	1
STABILITY	12%	5	0	3	1	0
BLENDING SUCCESS	19%	8	0	1	3	0
SECURITY	23%	10	0	0	0	3
		43		45	25	47

Figure XXIX. Pugh Matrix

In observation of the Pugh Matrix, we have finally converged to a final design solution (blade security tap) as it scored the highest punctuation in accordance to the customer requirements.

Manufacturing Cost Analysis

Given the estimated annual revenue of the company of the product we were analysing of $4 million, and an estimated sales price of $20, we have roughly approximated our annual production to 200,000 units in the use of Apriori. However, we have also changed the annual input to 100,000 and 10,000 to observe how important the volume of production was in the different costs associated to the production of our prototype. Below, I will first display the results of the variable and period costs for each of the three (figures XXX, XXXI, XXXII) and afterwards the fixed and capital costs (figures XXXIII, XXXIV, XXXV).

Variable Costs	**Current (USD)**
Material Cost	0.09
Labor	0.12
Direct Overhead	0.04
Amortized Batch Setup	<0.01
Logistics	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.25
Period Costs	
Indirect Overhead	0.10
SG&A	0.02
Margin	0.00
Piece Part Cost	0.38

Figure XXX. 200,000 units annual production associated variable costs

Variable Costs	**Current (USD)**
Material Cost	0.09
Labor	0.12
Direct Overhead	0.04
Amortized Batch Setup	0.01
Logistics	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.25
Period Costs	
Indirect Overhead	0.10
SG&A	0.03
Margin	0.00
Piece Part Cost	0.38

Figure XXXI. 100,000 units annual production associated variable costs

Variable Costs	Current (USD)
Material Cost	0.09
Labor	0.12
Direct Overhead	0.04
Amortized Batch Setup	0.06
Logistics	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.31
Period Costs	
Indirect Overhead	0.12
SG&A	0.03
Margin	0.00
Piece Part Cost	0.46

Figure XXXII. 10,000 units annual production associated variable costs

Fixed Costs	
Total Amortized Investments	0.02
Fully Burdened Cost	0.39
Capital Costs	
Total Capital Investments	15,096.26

Figure XXXIII. 200,000 units annual production associated fixed and capital costs

Fixed Costs	
Total Amortized Investments	0.03
Fully Burdened Cost	0.41
Capital Costs	
Total Capital Investments	15,096.26

Figure XXXIV. 100,000 units annual productions associated fixed and capital costs

Fixed Costs	
Total Amortized Investments	0.30
Fully Burdened Cost	0.76
Capital Costs	
Total Capital Investments	15,096.26

Figure XXXV. 10,000 units annual productions associated fixed and capital costs

Thanks to Apriori, we can know that at 100,000 annual production the variable costs are saturated and that therefore producing one more unit does not change the unitary cost ($0.38). However, if we had a smaller production level (10,000 annual units), our unitary price would ascend to $0.46.

The difference becomes even higher taking into account the fixed costs with a difference of $0.35 per unit. As our company (Bella) makes a revenue of $4 million and this hand blender is one of its most important products, we could find reasonable an annual production of 100,000. This means we would have an extra production cost in the final product of $0.41.

CAD Modelling of the New Product

Our redesigned part is the blade security tap as it is the final solution we converged to with the Pugh matrix. Below you can see screenshots of the CAD model and a hand drawn-sketch of how this part will be assembled with the whole product.

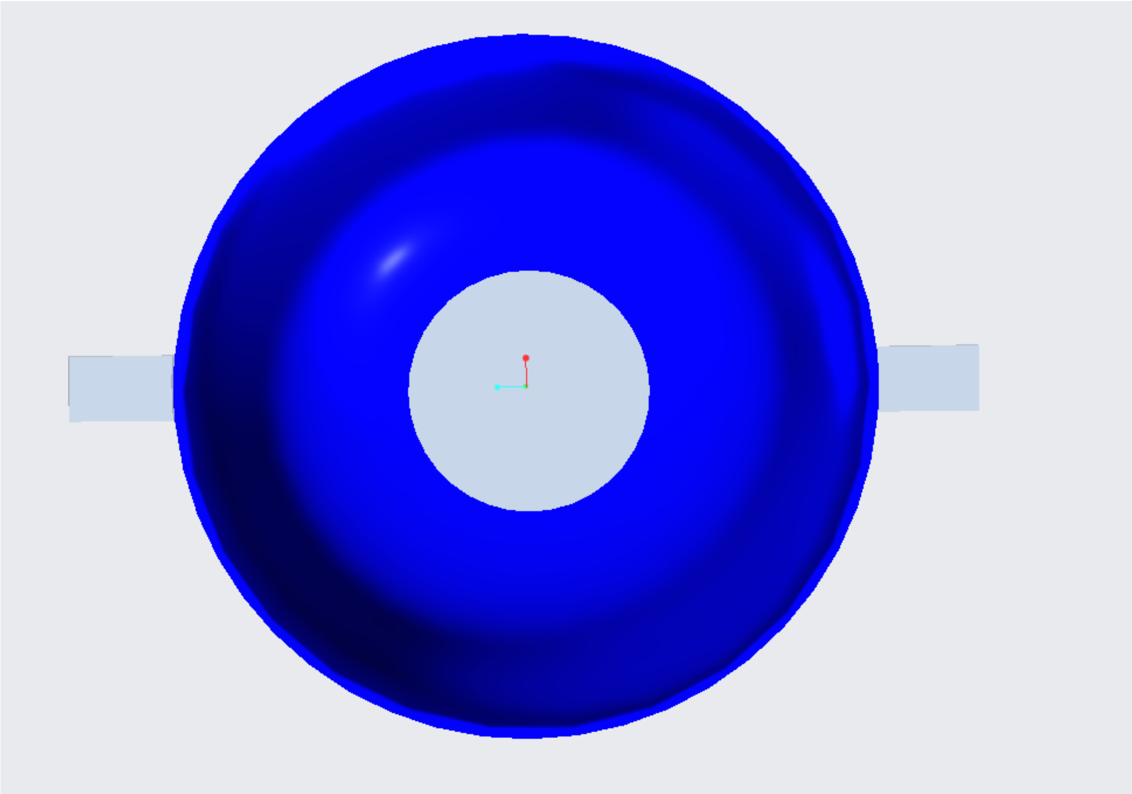


Figure XXXVI. Bottom view

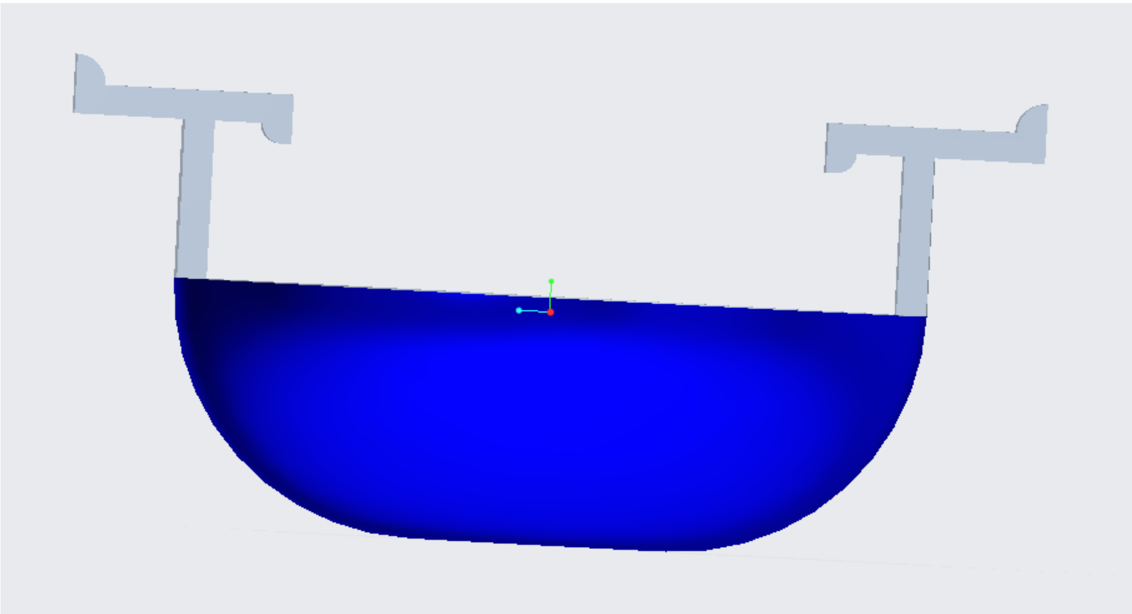


Figure XXXVII. Side view

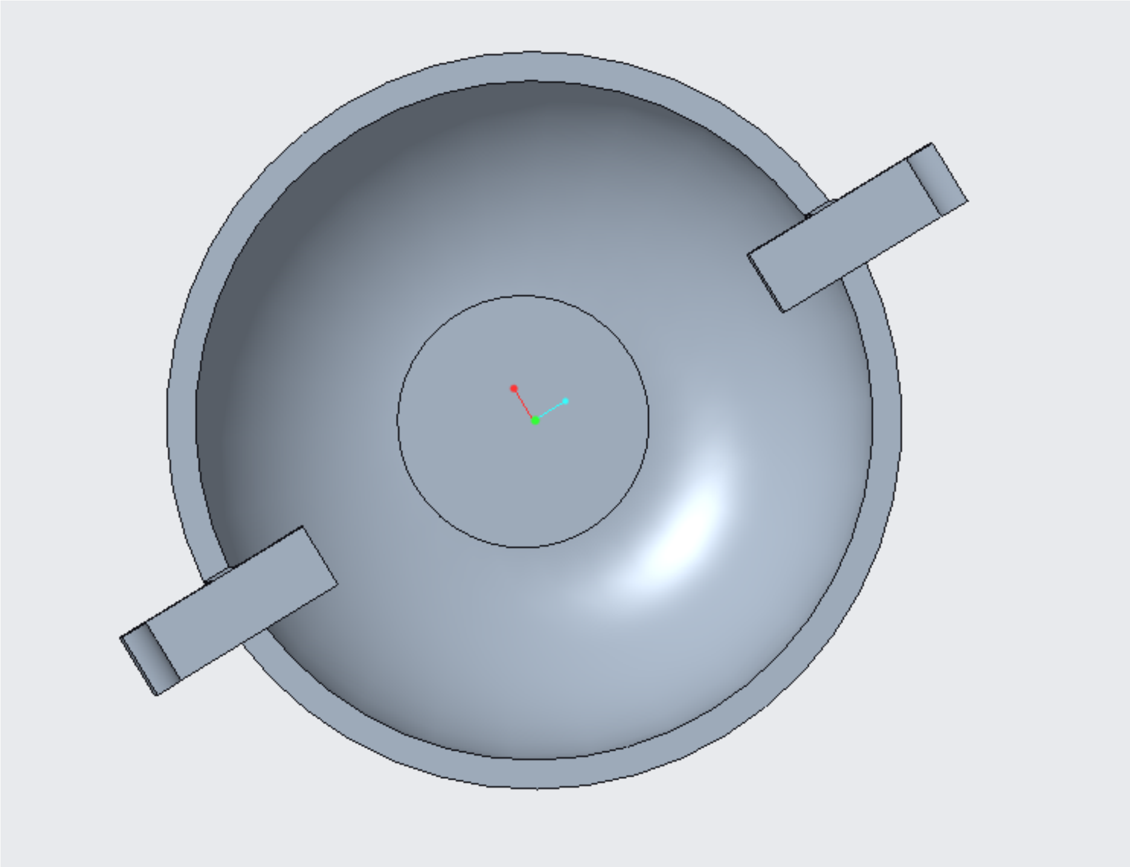


Figure XVIII. Top view

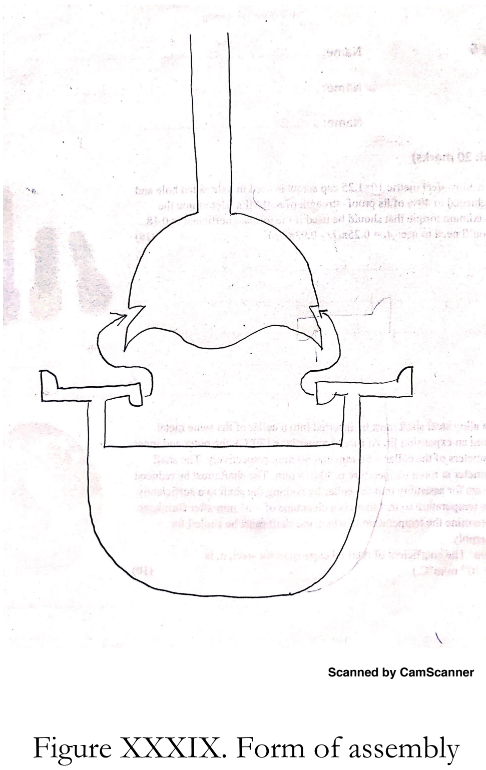


Figure XXXIX. Form of assembly

Physical prototype

In the pictures below you will be able to observe the physical prototype printed in the Innovation Studio.

Figure XL. Side view

Figure XLI. Top view

Figure XLII. Bottom view

CONCLUSIONS

Design of experiment

A factorial experiment is one in which we control several factors and investigate their effects at each of two or more levels. Factorial design consists of making an observation at each of all possible combinations that can be formed at different levels of factors.

Randomization and replication are two basic principles of experimental design. In an experiment with a large number of tests, it´s important to randomize the order in which the specimens are selected for testing, to reduce or minimize variability. It removes unconscious bias and allows for un-biased observations. With regards to replication, repetition of experiment is required because it allows us to obtain an estimate of the experimental error before embarking on a major experimental program.

For our blade security tap we have selected the time of assembly as the response of our 2^2 design. Our two factors selected have been the material used for the tap (levels: steel or plastic), and the size of the tap (small or big).

The calculation of the main effect of the factors is the following:

$$Main\ effect\ of\ the\ material = (\Sigma\ time\ with\ steel - \Sigma\ time\ with\ plastic)/(half\ the\ number\ of\ runs\ in\ the\ experiment$$

$$Main\ effect\ of\ the\ size = (\Sigma\ time\ with\ small\ size - \Sigma\ time\ with\ big\ size)/(half\ the\ number\ of\ runs\ in\ the\ experiment$$

We estimated the small size and the steel as the high levels of both factors having time of assembly as the response. Below you can see the matrix of our experimental design.

TREATMENT COMBINATION	MATERIAL	SIZE	CALCULATION COLUMN	REPLICATE 1	REPLICATE 2	AVERAGE
A	STEEL	SMALL	+	1,2	1,3	1,250
B	PLASTIC	SMALL	-	0,9	1	0,950
C	STEEL	BIG	-	0,85	1	0,925
D	PLASTIC	BIG	+	0,7	0,75	0,725
CONTRAST	0,5	0,550	0,100			
EFFECT	0,25	0,275	0,05			

Figure XLIII. Design of experiment

The interpretation of the results is that if we change the material from steel to plastic, the assembly time is increased by 0.25 seconds. Meanwhile, changing from a big to a small tap increases it by 0.275

seconds.

The next step is to determine if the effects are significant. We will estimate the standard deviation of the averages, also called *"standard errors"*.

$$s.e = (\frac{1}{4(n-1)})\sum_{i=1}^{2}\sum_{j=1}^{2}(y_{ij} - \overline{y_{ij}})^2$$

Our standard error is **0.053**

The approximate 95% confidence interval = Factor effect±2(s.e)

Factor material= 0.25±(2*0.053)=[0.144,0.356]

Factor size= 0.275±(2*0.053)=[0.169,0.381]

Interaction size-material=0.05±(2*0.053)=[-0.056,0.156]

From this we can conclude that the effects of material and size are significant because their intervals do not include 0.

And the last step of the experimental design is the response diagram (figure XLIV). In it, it is easy to observe the little interaction between variables.

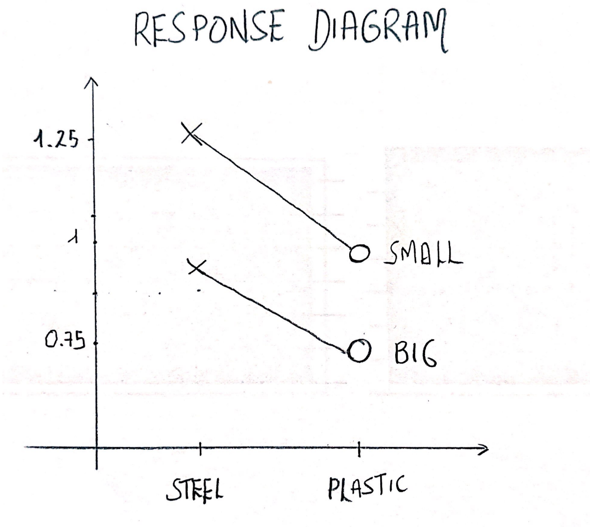


Figure XLIV. Response diagram

Comparison of the original product with the re-designed component

Figure XLVI. Original product

Figure XLVII. Re-designed product

Our re-design has ultimately focused on an improvement of function, with a new feature that could result very attractive to the niche market that buys this kind of products more often. With regards to cost, the *Apriori* output has given an extra cost of $0.46 to the product that could be added to the ending retail price in pursuit of not damaging margins. However, if we put in the balance the improvement of our product and its little increase in price, I believe the result will be an increase of market share, which is the ultimate objective.