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UNIVERSIDAD PONTIFICIA
ICAI

GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

RE-DESIGN FOR MANUFACTURABILITY: PROCTOR SILEX 72500RY FOOD CHOPPER

Autor: Guillermo López-Silvarrey Montero

Director: Leon Liebenberg

Madrid

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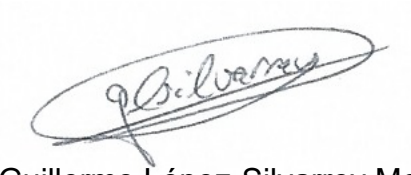

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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

RE-DESIGN FOR MANUFACTURABILITY: PROCTOR SILEX 72500RY FOOD CHOPPER

Autor: Guillermo López-Silvarrey Montero

Director: Leon Liebenberg

Madrid

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REDISEÑO PARA LA MEJORA DE LOS PROCESOS DE FABRICACIÓN DE UN PROCESADOR DE ALIMENTOS

Autor: López-Silvarrey Montero, Guillermo.

Director: Liebenberg, Leon.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

RESUMEN DEL PROYECTO

El objetivo principal de este proyecto es el rediseño y optimización de un producto existente, mediante el reemplazo o eliminación de una serie de piezas, con el fin de lograr una simplificación de sus procesos de fabricación, un ahorro en costes y materiales y un aumento de su funcionalidad.

El producto elegido para este estudio será la picadora de alimentos modelo 72500RY, de la marca norteamericana Proctor Silex. Se trata de un procesador de alimentos, más concretamente de un cortador de comida, que se puede enmarcar dentro de la subcategoría de los cortadores de pequeño tamaño, así como también de los de bajo coste. Ambas propiedades suponen elementos característicos de este producto, que lo diferencian del resto de cortadores que hay en el mercado, haciéndolo atractivo para sus potenciales compradores.

Para llevar a cabo este proceso, es necesaria la realización de un profundo análisis del producto, su funcionamiento y sus procesos de fabricación. En primer lugar, se realiza un estudio de mercado, con el fin de establecer la importancia que tiene el producto en su sector y obtener una estimación del volumen de ventas anuales, así como de comparar sus características con las de las principales cortadoras del mercado. De este análisis se observa que, a pesar de presentar ciertas carencias con respecto a sus competidores en cuestiones como la capacidad o la potencia, este producto destaca especialmente por ser de los más pequeños, ligeros y económicos del mercado. Además, se obtiene una estimación de un volumen de ventas de unas 254.000 unidades por año, cifra que será útil para cálculos posteriores.

Una vez analizado el contexto del producto, es preciso llevar a cabo un profundo análisis físico de éste. Para ello, en primer lugar, se realiza un minucioso desmontaje del aparato y un listado con todas sus piezas. Éste consta de cuatro partes fundamentales: el bol, la tapa, las cuchillas y la base. Esta última, la cual será el principal objeto de estudio, se compone de una carcasa formada por varias piezas de plástico, dentro de la cual se encuentra una placa interna que sostiene un motor y varios engranajes, y, en una cavidad aparte, un interruptor que acciona el mecanismo. Seguidamente, se añade a este listado el material de cada una de estas partes, así como el método empleado para su fabricación. Las piezas de plástico que conforman la carcasa y las placas internas de la base, así como

la tapa y el bol, están fabricadas mediante moldeo por inyección, empleando fundamentalmente polipropileno y ABS. Por otra parte, también hay piezas de aluminio y acero fabricadas por forjado y mecanizado, que constituyen las cuchillas y el eje de éstas. El resto de piezas, al ser piezas normalizadas y no específicas para este producto (tornillos, engranajes, …), se asume que han sido compradas a un fabricante especializado.

A continuación, se elabora un estudio de las características del producto. Mediante un despliegue de la función calidad (QFD), se relacionan las características físicas mensurables de la máquina con los posibles requerimientos del usuario, y se comparan con las de los principales competidores. El objetivo de esta fase es identificar y valorar las posibles áreas de mejora, y seleccionar las más relevantes. De esto se obtiene que las mejoras que tendrán una mayor repercusión para el usuario son la reducción del coste de los materiales, de la altura del dispositivo y del calentamiento provocado por el uso y el aumento del agarre de la base a la superficie de apoyo. Al no presentar carencias en ninguna de las dos últimas, los esfuerzos de rediseño se focalizarán fundamentalmente hacia la altura del electrodoméstico y el gasto en materiales. La primera es importante debido a que se busca una reducción del tamaño, tanto por funcionalidad como por ahorro de costes. Además, lo que lo hace preferible frente a la reducción de la anchura o de la profundidad es que conlleva a mayores un aumento de la estabilidad, mientras que en los otros dos casos se provocaría una reducción de ésta. Por tanto, es necesario valorar nuevas formas de disponer los elementos internos del dispositivo con el fin de reducir esta medida lo máximo posible.

Por otra parte, la reducción del gasto en plástico se puede llevar a cabo de diversas maneras. En primer lugar, mediante una disminución de la cantidad, que consistiría, aparte de la ya mencionada rebaja de la altura, en una simplificación de las formas y del número de piezas, en la medida de lo posible. Asimismo, se busca en el software CES Edupack si existe algún material de características similares al polipropileno que nos permita una reducción del precio de éste, para lo cual se encuentra el polietileno de alta densidad (PE-HD). Por último, otro posible cambio a valorar reside en el método de fabricación. Se decide mantener el moldeo por inyección, aunque empleando la colada caliente, que permite un mayor aprovechamiento del plástico y una mayor velocidad de producción, optimizando así el proceso de inyección. Además, una simplificación del ensamblaje permitiría también ahorrar costes y tiempo en este proceso.

Posteriormente, el producto se somete a un proceso de diseño para ensamble (DPE). Esto permite identificar si es posible combinar o eliminar alguna de las piezas, con el fin de reducir tanto el tiempo de fabricación como el gasto en cantidad de material y en ensamblaje. De este análisis se concluye que es posible combinar las cinco piezas de plástico que componen la base, de tal forma que se pueden eliminar hasta tres de ellas. De esta manera, además de reducir la necesidad de piezas de plástico, se disminuye de forma significativa la cantidad de tornillos.

Una vez decididas las piezas a modificar, se procede a elegir y desarrollar el diseño de las nuevas piezas. En primer lugar, se realiza un modelo 3D de las cinco piezas originales,

empleando el programa Creo Parametric, con el fin de analizarlas y compararlas con las nuevas. Una vez diseñadas, se emplea el software aPriori, del cual se obtiene una completa estimación de sus costes de fabricación. Posteriormente, se esbozan y se comparan los posibles diseños de las nuevas piezas. De estos bocetos, se elige el más adecuado y se realiza el modelo 3D de las nuevas piezas. La nueva base se compone de dos partes de polietileno: una carcasa más compacta y simple que la anterior, y una tapa "en L" que cubre las caras inferior y posterior de la base. Además, los tornillos restantes se sustituyen por encajes a presión, salvo aquellos que sostienen el motor, de tal forma que su número se reduce de quince a tan sólo dos tornillos. A continuación, se realiza el primer prototipo físico mediante impresión 3D, con el fin de acoplarlo con el resto de piezas y probar su funcionamiento. Tras varias modificaciones y distintos prototipos, se obtiene el diseño definitivo de las nuevas piezas.

Finalmente, se realiza el estudio de los costes de fabricación de las nuevas piezas con aPriori, y se compara con las anteriores. El resultado obtenido demuestra un ahorro en plástico de $0.95 por unidad, cuyo coste disminuye de $2.18 a $1.23, lo cual, de acuerdo con las estimaciones de ventas, implica un ahorro en material de unos 241300 dólares anuales. Además, se reduce el tiempo de ensamblado a menos de la sexta parte, lo cual permite un mayor volumen de producción y un ahorro significativo de gastos de ensamblado, que representan una parte importante del coste del producto. Asimismo, la funcionalidad del dispositivo también se mejora. La reducción tanto de volumen como de peso lo hacen más manejable y fácil de almacenar, y su centro de gravedad más bajo, debido a la disminución de la altura, lo hace más estable.

RE-DESIGN FOR MANUFACTURABILITY OF A FOOD PROCESSOR

The main objective of this project is the re-design and optimization of an existing product, by the replacement or removal of a series of parts, in order to simplify its manufacturing processes, to minimize its costs and waste of materials and to enhance its functionality.

The chosen product for this study is the Proctor Silex 72500RY food chopper. This is a food processor that can be included in the mini-food chopper subcategory, and can also be considered as low-cost. Both of these properties are characteristic features of this product that make it different from other choppers in the market, making it attractive for its potential buyers.

In order to carry out this process, it is necessary to perform a deep analysis of the product, its functioning and its manufacturing processes. First of all, it is done a market analysis, with the goal of stating the product's importance in its sector and obtaining an estimation of the annual volume of sales, as well as comparing its features with the main choppers in market. From this analysis it is noted that, in spite of presenting several lacks with respect to its competitors in terms of capacity or power, this product specially highlights for being one of the smallest, lightest and most economical in the market. Moreover, it is obtained an estimation a volume of sales of around 254,000 units per year, cypher that will be useful for later calculations.

Once the context of the product is analyzed, it is precise to carry out a deep physical analysis of it. Therefore, first of all, it is realized a thorough disassembly of the appliance and a list of all its parts. It consists of four main parts: the bowl, the lid, the blades and the base. The last one, which will be the main object of study, is composed of a case formed by several pieces of plastic, in which there is an internal plate that holds a motor and several gears and, in an apart cavity, a switch that actuates the mechanism. Next, the material of each of those parts, as well as the methods used for their manufacturing, are added to that list. The plastic pieces that form the case and the internal plates of the base, as well as the lid and the bowl, are manufactured by injection molding, mostly using polypropylene and ABS. On the other hand, there are also aluminum and steel parts manufactured by forging and machining, which are the blades and their shaft. The rest of the parts, as they are normalized and not specific for this product (screws, gears, …), it is assumed that they have been bought to a specialized manufacturer.

Subsequently, a study of the characteristics of the product is elaborated. In a quality function deployment (QFD), the relationship between the physical features of the appliance and possible customer requirements is defined. In this matrix, the device is also compared with its main competitors. The objective of this phase is to identify and assess possible areas of improvement, and to select the most relevant. From this it is inferred that the improvements that will have greater impact for the user are the reduction of material costs, of the height, of the heating provoked by the machine's functioning and the increase of the friction with the support surface. As it does not present any lack on the two last features, the re-designing effort will mainly focus on reducing the height and the cost of materials. The first of them is relevant because a reduction of the size is pursued, both for functionality and for costs reduction. Moreover, a reduction of height implies an

increase of stability, which makes it preferable than reducing other dimensions that would imply a decrease of it. Consequently, it is necessary to explore new ways to locate the internal elements of the base in order to reduce this measure to its minimum.

On top of that, the reduction of the need of plastic can be carried out in several ways. First, by a diminution of the quantity, that would consist, apart from the aforesaid reduction of the height, in a simplification of shapes and number of parts. Moreover, the software CES Edupack is used to search a material with properties that are similar to polypropylene and that can allow a reduction of its price, for what high-density polyethylene (PE-HD) is found. Last, another possible change to assess is the manufacturing process that is employed. Injection molding is going to be kept, but hot runners are going to be employed, which permits a lower scrap rate and higher production velocity, optimizing the injection process. Also, simplifying the assembly would make possible to save money and time in this process.

Afterwards, the product is taken into a design for assembly (DFA) process. This allows to identify if it is possible to combine or remove any of the parts, with the aim of reducing both the manufacturing time and the expenditure on material and assembly. From this analysis it is concluded that it is possible to combine the five plastic parts that form the base, so that up to three of them can be eliminated. In this way, apart from reducing the necessity of plastic parts, the quantity of screws used is significantly lowered.

Once the pieces to modify are identified, it is time to choose and develop the design of the new parts. At first, a 3D model of the original parts is created, using the program Creo Parametric, so as to analyze and compare them to the new ones. Once they are designed, aPriori software is used to obtain a full estimation of their manufacturing cost. Subsequently, potential designs for the new parts are sketched and compared with each other. From these outlines, the most adequate is chosen and CAD modeled. The new base is composed of two polyethylene parts: a more compact and simpler case and a L-shaped lid that covers the inferior and rear sides of the base. Furthermore, the remaining screws are substituted for snap fits, except from those that hold the motor, so that their number is reduced from fifteen to two. Next, the first physical prototype is produced by 3D printing, with the aim of assembling it with the rest of the parts and try its functioning. After several modifications and different prototypes, the final design of the new parts is obtained.

Finally, a study of the costs of the new parts is made with aPriori, and it is compared with the previous one. The obtained result shows that there is a saving in plastic of $0.95 per unit, whose cost diminishes from $2.18 to $1.23, which, according to our annual sales estimations, implies a saving of $241,000 per year. Additionally, time of assembly is reduced to less than the sixth part, what permits a greater volume of production and a significant save in assembly costs, which imply an important part in the product cost. Likewise, the functionality of the appliance also improves. Both the volume and the weight reduction make it more manageable and easier to store, and its lower center of gravity, owing to the height reduction, makes it more stable.

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Introduction

The main objective of this project is the redesign and optimization of an existing product, for which the Proctor Silex 72500RY food chopper was chosen. The way this task is going to be carried out is the following. First, it is necessary to do a deep analysis and research of the product characteristics, strengths and weaknesses, in order to decide the areas in which it can be improved. Then, we will have to decide what parts are going to be substituted, adapted or removed so as to achieve those objectives, and also to optimize costs and assembly processes.

Once we have an idea of what is going to be changed, it will be time to CAD-model the new parts and to manufacture the first prototypes. In order to do that, we were given a budget of $60 and 500g of 3D filament at the Innovation Studio in the Mechanical Engineering Laboratory, which belongs to the University of Illinois at Urbana-Champaign. The models will be designed using Creo Parametric, which will also be provided by the aforesaid organism, and then they will be adapted for 3D printing using Cura software.

Finally, once the final prototype is manufactured and ready to operate, it will be time to analyze the results and to compare them to the features of the original product.

1. Disassembly of the product

The product that is going to be studied is the food chopper model 72500RY by Proctor Silex. At first sight, it consists of four well differenced parts, which are the cover (1), the blade (2), the bowl (3) and the base (4), as it can be seen in Figure 1.

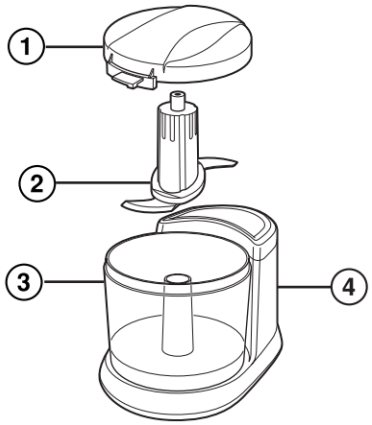


Figure 1. Parts of the product

In order to explore its mechanism, it was necessary to disassemble the base. It incorporates four screws that are hidden below four little rubber stoppers. After removing those screws, the bottom plate could be taken off. Figure 2 represents what could be seen when the cover was extracted.

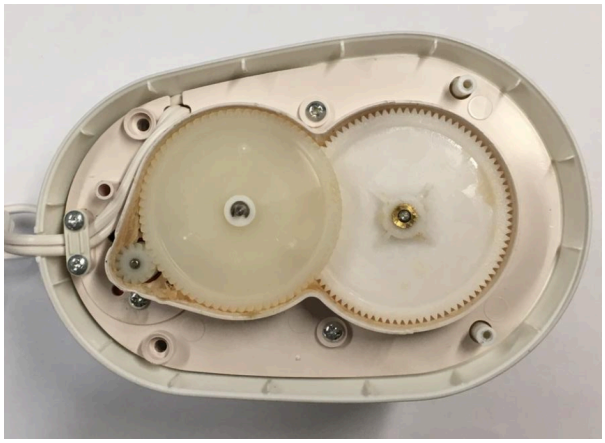


Figure 2. Base once the bottom lid was removed.

As we can see, there are three gears. The first one is a small one that is connected to the shaft of the rotor, and that moves the second one, which is quite bigger. The third one is connected to a smaller part of the second. This mechanism is used to reduce the velocity of the shaft, which implies a bigger torque so that the blades are able to cut the food in the cup.

After removing all the screws that can be seen on Figure 2, the second plate can be disassembled. Inside, there is a motor that moves the smallest of the gears and that is screwed to the aforesaid plate. It is connected to a switch, which is actuated by the bowl lid when it is turned. The switch is located in an additional cavity that is under a top cover attached to the base with the help of four screws. In that cavity, there is also a torsion spring that interacts with the lid of the bowl when it actuates the switch, in order to lead it back to its initial position.

Figure 3. Motor.

Figure 4. Switch and how it is activated.

In the following table, there is a list of all the materials that were found in the product..

	PART	QTY.	NOTES
1	Main cover	1	Injection-molded
2	Top cover	1	Injection-molded
3	Bottom cover	1	Injection-molded

4	Gear-holding plate	1	Injection-molded
5	Gear	3	Several diameters (70 mm, 65 mm and 10 mm)
6	Shaft	1	
7	Motor	1	70 W
8	Switch	1	
9	Torsion spring	1	120 degrees angle, 0.373” of outside diameter, 1” of length at max. torque.
10	Stopper	4	
11	Ring 1	1	Keeps one of the gears on its axis
12	Ring 2	5	
13	Ring 3	1	Serves as a support for the shaft
14	Screw	15	Rounded head blunt screws for sheet metal, 18-8 stainless steel, number 4 size, ½” long
15	Cable holder	1	Injection-molded
16	Blade	1	
17	Cup	1	Injection-molded
18	Lid	1	Injection-molded
19	Cables	2	

Table 1. Bill of materials.

Figure 5. View of all the parts of the disassembled product.

2. Technical and sales information

A food processor is an electric appliance that is used for chopping, mixing or pureeing. It generally consists of several blades that are located around a shaft that turns at high velocity in order to chop the food. The demand of these sets has increased a lot in the last decades, because nowadays it is increasingly frequent to apply technology to daily tasks. However, in the past five years the revenue of this industry has declined by -0.9%, reaching 1.2 billion dollars in 2019. (Kalyani 2019)

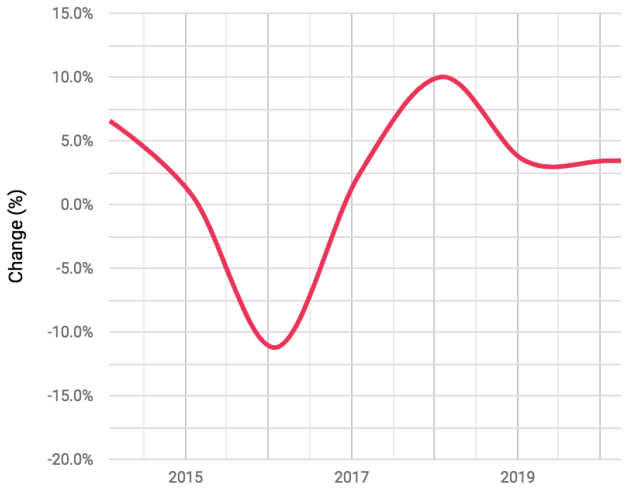


Figure 6. Variation of the revenue of the food processor manufacturing industry in the last 5 years.

There are many kinds of food processor. In this study, we are focusing on choppers, which are classified in the category of "blenders and slicers", that corresponds to a 41.1% of this whole industry, that is to say, to an approximate revenue of 493.2 million dollars in 2019. This is represented in Figure 7. (Kalyani 2019)

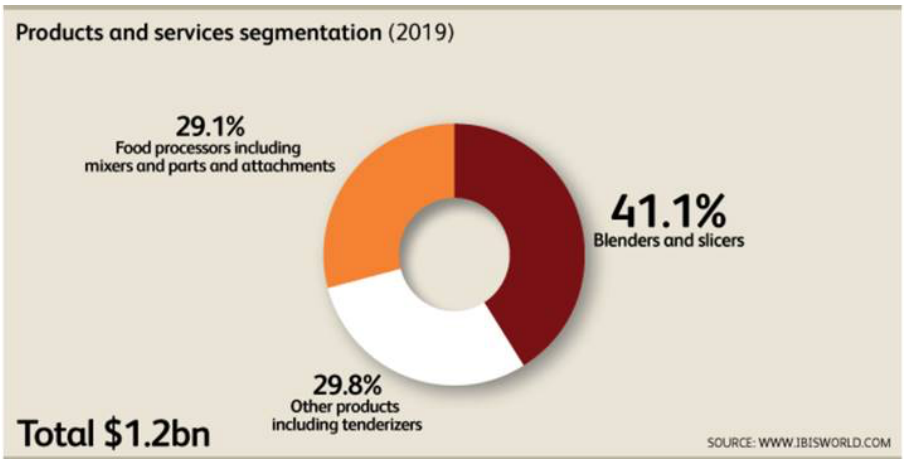


Figure 7. Segmentation of the food processors' market.

Inside this category, there are several different types of processors. Choppers are compact appliances, that have as objective not only cutting food into small pieces but also being small and simple. They represent a 15.12% of this submarket, as we can see in Figure 8. (Jackson 1992)

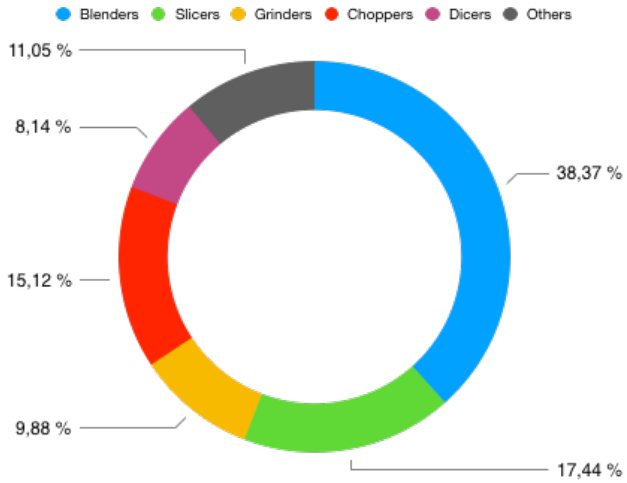


Figure 8. Segmentation of the blenders and slicers submarket.

This percentage represents an amount of 74.97 million annual revenue, from which a 42% corresponds to mini-choppers, considering in this category all of them that have a capacity of less than 3 cups (711 ml). Consequently, the market niche that we are studying involves an annual revenue of 31.5 million dollars.

In the following table, the product of study and its main market competitors have been picked:

	Black+Decker Ergo EHC650B	**Cuisinart Mini Prep DLC-1**	**Ninja Express Chop NJ100**	**Oster Classic FPSTMC3321**	**Proctor Silex 72500RY**
Dimensions (inches)	5.5 x 5.5 x 9.1	4.63 x 6.25 x 8.00	10.1 x 5.7 x 5.7	8 x 7.5 x 5	7.09 x 4.72 x 5.12
Weight (lb)	3.08	2.89	1.2	4	1.6

Capacity (cups)	3	2.6	2	3	1.5
Power (W)	150	110	200	150	70
Price ($)	24.99	34.95	17.99	30.92	14.89

Table 2. Main mini food chopper models and their characteristics.

As we can see in Table 2, the product of study is the cheapest one in the market. This is the most important feature of this product, as it is one of the things that customers most require when buying a mini food chopper. However, this advantage entails a handicap in other attributes, such as power or capacity, in which it is at a clear disadvantage with respect to its competitors. Moreover, in terms of size and weight it is also one of the most practical. Bearing this in mind, it can be said that what can make this product highlight among its competitors are its simplicity and low price.

As there was no available data about the market share of these products, we are going to assume an average price of $24.78 per product, which is the arithmetic average of the models in Table 2. This means that an approximate number of sales per year could be 1.27 million devices. If we also presume that Proctor Silex 72500RY has a fifth of the market share (which is not a real value but can give us an approximate sight of the sales volume of our product), it can be supposed that the company sells an average close to 254 thousand choppers per year.

As it has been said in previous paragraphs, this number is predicted to grow due to several factors. Firstly, it will be influenced by the fact that nowadays technology is increasingly accessible and it is more and more commonly used for daily purposes. Besides, the manufacturing and distribution costs of this kind of products are progressively decreasing as the industry and its technology developes, so the prices of these appliances are prone to get lower as well. However, there exist some possible threats to this growth. The most important one is the emergence of multi-function devices that can chop aliments but also cut or blend them in other ways. Given that simplicity is the main objective that customers look for, those appliances can also be a practical solution for them.

3. Manufacturing process

The Proctor Silex 72500RY food chopper is manufactured and marketed by Hamilton Beach Brands, Inc. It is a holding company that designs, produces and distributes all kind of small electric household appliances under the Hamilton Beach, Proctor Silex, Eclectrics Collection and TrueAir brands. It was founded in 1910 in Rancine, Wisconsin, but it was not until 1990 when it merged with the Pennsylvanian company Proctor Silex to become the largest U.S. manufacturer of small kitchen appliances. Nowadays, it is based in the suburbs of Richmond, Virginia, but it has headquarters all around North America, including Canada and Mexico, which are the countries in which their products are mainly sold.

The manufacturing process of this product consist on the following steps. First of all, all the materials are bought. The aim is to get as much materials as possible at the lowest price. Also, parts that will not be manufactured by the company, such as the screws, motors, … , are purchased to a third party. Apart from the cost of the materials, transportation and storage costs must be considered. Besides, at this stage they establish the objectives of the production and plan the use of each of the materials and purchased parts for each step of the process.

Afterwards, each part of the final product must be manufactured. They use several techniques for this step.

Plastic parts (case, cup, lid, internal plates, …) are produced by injection molding. This process consists in the injection of a molten material (a polymer, in this case) into a closed metal mold. There, the material solidifies, obtaining the desired part. This technique is very common for mass productions, since, once the initial investment is assumed, which is usually quite big, the cost per unit is extremely low. Besides, it has a very low scrap rate. Only additive manufacturing processes such as 3D printing have a lower rate, but they are not practical for mass production.

In order to reduce costs, these parts are produced in China, where the workforce and the cost of this kind of processes are the cheapest. Another strategy that they use to make the production cheaper is the use of thermoplastics (PP and ABS), as they can be melted, cool and solidify, and then be melted again without burning. This makes possible a process called “re-grind”, which consist on reusing the waste material generated in the production of the parts, so the scrap rate is even lower. This is usually limited by quality control

departments, so if too much re-grind is produced it can also be sold to other companies that also want to reduce their material costs. It is mainly used for low-quality parts that do not have specific performance requirements.

On the other hand, while the plastic parts are manufactured by the company, most of the metal parts are purchased. However, some of them are manufactured by forging. Forging is a manufacturing technique that consists of shaping metal by plastic deformation. The material is forced into the desired shape with the help of a hammer or a die, either in cold or after heating the metal.

As forgings can be nearly any shape, it helps avoiding weldments or fastenings, so it makes possible to save material and to gain strength. Also, it is a cheaper method than those two when produced in high volume. Furthermore, parts produced by forging are stronger than with any other method, as the grain flow gets the shape of the contours of each part, what gives it a special strength.

In the case of the blades, they are previously submitted to a thermal treatment in order to gain strength. The steel is heated to temperatures of around 2000ºF and then is quenched in water for a quick cooling. After that, a very fragile material is obtained, as it is mostly formed of martensite, so it is necessary to leave it some hours tempering to improve its mechanical properties. Then, the metal can be stamped into a die with the help of a hammer.

Another technique used for some of the metal parts (more concretely, the metal shafts) is machining. This is a subtractive technique, as it consists of shaping a metal by removing material with a cutting tool. This means that has a higher scrap rate, which represents its main drawback. However, there are several features that make it worth to use this method. Its main benefits are “its high precision, allowing a multitude of shapes, preserving the mechanical properties of the material, achieving a good finishing texture, besides requiring little preparation time, being carried out with few tools and being easy to automate.” (Association of Professionals for Competitiveness in Machining (ASPROMEC) 2018)

Once all the parts are manufactured, it is time to put them all together. First, the ones that have been produced in Asia have to be sent to the assembling plants in North America, so that this process can be carried out. The costs of assembly usually represent from a 10 to a 50% of the total manufacturing costs.

“During the production stage, it is essential to observe the quality standards and to control their fulfillment. For this phase to go as planned and to avoid problems, it is necessary to do a work of observation of the environment, so that changes can be anticipated and an action plan can be drawn in order to know how to act at all times to continue working for the accomplishment of the objectives.

[…]

The last stage is oriented towards the commercialization of the product. Transportation, storage and intangible elements associated with demand are the three main variables to be considered at this stage. Once the product has been delivered, it cannot be forgotten that it must be carried out a control task that allows to know if what has been delivered meets the objectives set and with the quality standards that the client demands.” (EAE Business School 2017)

This product is shipped by land, either by train or by truck, all around North America, where it is sold in electronics stores, department stores and online platforms such as Amazon.

4. Quality Function Deployment

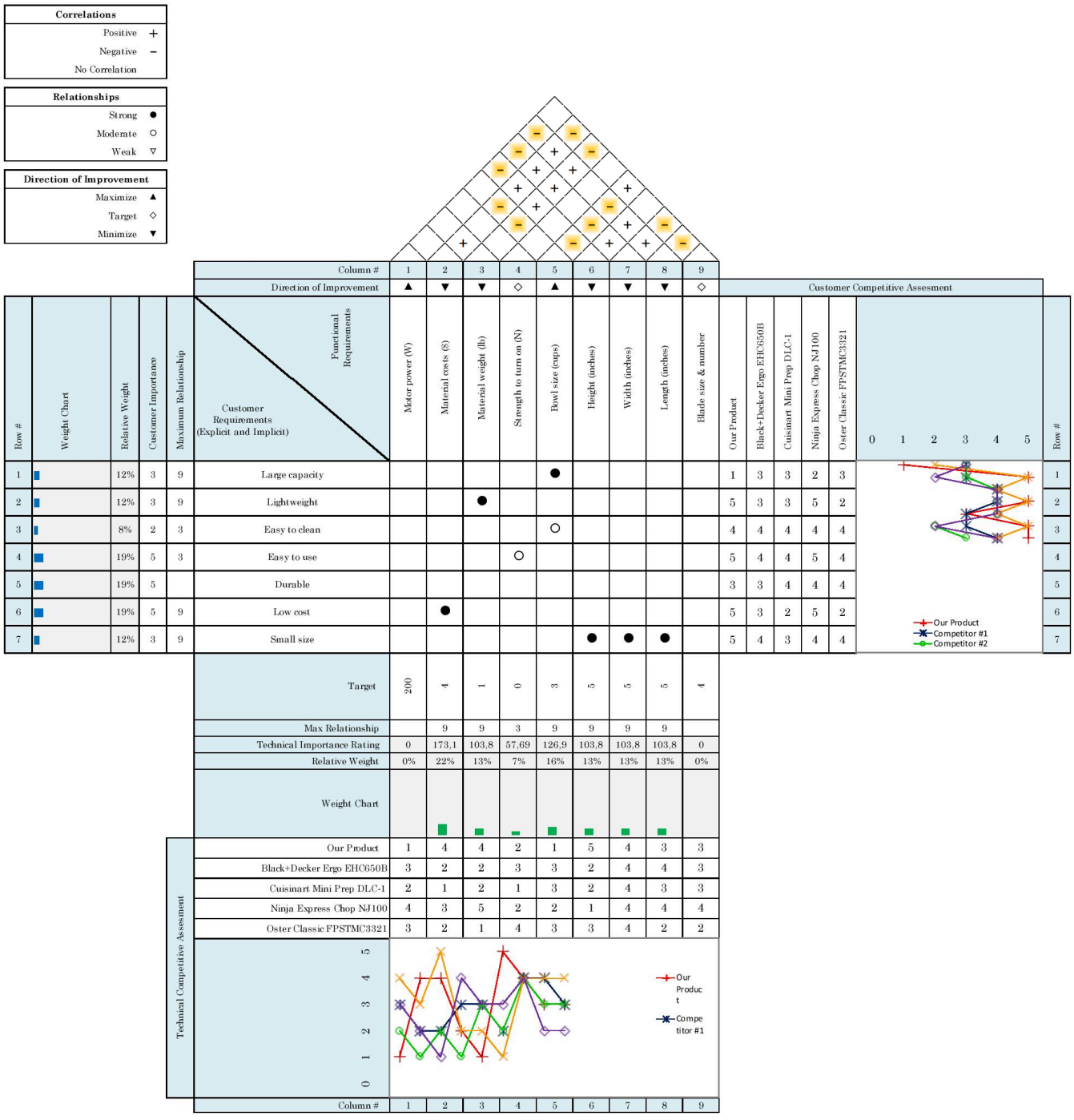


Figure 9. House of Quality (HOQ) of the product.

This diagram is a House of Quality of the product, which is used to define the relationship between the product features and the customer requirements. In order to do that, some of the characteristics of the product have been collected in the top of the matrix, and the main customer desires are written on the left side. This has all been computed, obtaining some relevant information for the re-designing project.

First of all, we are going to focus on the left part of the chart. On that side, there is an estimation of the importance that each of the customer requirements has and their weight in the whole project.

Row #	Weight Chart	Relative Weight	Customer Importance	Customer Requirements (Explicit and Implicit)
1		12%	3	Large capacity
2		12%	3	Lightweight
4		8%	2	Easy to clean
5		19%	5	Easy to use
6		19%	5	Durable
7		19%	5	Low cost
8		12%	3	Small size

Figure 10. Importance of each of the customer requirements.

As it can be seen, for this study the aspects that have been considered to be more important have been the simplicity, the durability and the low cost. Features related to the size, the weight and the capacity have been considered as well.

On top of that, on the right side of the chart there is an evaluation of those aspects, and a comparative between our product and its four main competitors.

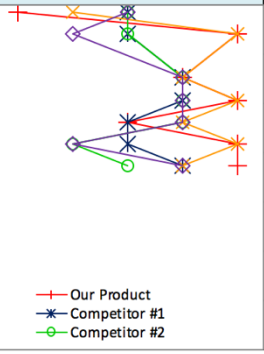
Customer Requirements (Explicit and Implicit)	Our Product	Black+Decker Ergo EHC650B	Cuisinart Mini Prep DLC-1	Ninja Express Chop NJ100	Oster Classic FPSTMC3321	0 1 2 3 4 5	Row #
Large capacity	1	3	3	2	3		1
Lightweight	5	3	3	5	2		2
Easy to clean	4	4	4	4	4		4
Easy to use	5	4	4	5	4		5
Durable	3	3	4	4	4		6
Low cost	5	3	2	5	2		7
Small size	5	4	3	4	4		8

Figure 11. Evaluation and comparative of customer requirements.

As we can see, our product if one of the best in terms of functionality and low cost, but has lower capacity than the others. In the same way, our device has been compared to its competitors regarding to their product features.

Column #	1	2	3	4	5	6	7	8	9
Direction of Improvement	▲	▼	▼	◇	▲	▼	▼	▼	◇
Functional Requirements	Motor power (W)	Material costs ($)	Material weight (lb)	Strength to turn on (N)	Bowl size (cups)	Height (inches)	Width (inches)	Length (inches)	Blade size & number
Our Product	1	4	4	2	1	5	4	3	3
Black+Decker Ergo EHC650B	3	2	2	3	3	2	4	4	3
Cuisinart Mini Prep DLC-1	2	1	2	1	3	2	4	3	3
Ninja Express Chop NJ100	4	3	5	2	2	1	4	4	4
Oster Classic FPSTMC3321	3	2	1	4	3	3	4	2	2
0 1 2 3 4 5	Our Product; Competitor #1; Competitor #2; Competitor #3								
Column #	1	2	3	4	5	6	7	8	9

Figure 12. Evaluation and comparative of product features.

Apart from this, the central part of the graphic, which is one of the most important ones, is the one that relates each customer requirements with the product features. It is shown in Figure 13 which of them are related and the extent to which they are (see the legend on Figure 9). Moreover, on top of the matrix there is a pyramid that represents the dependence of the functional requirements to each other.

Column #	1	2	3	4	5	6	7	8	9
Direction of Improvement	▲	▼	▼	◇	▲	▼	▼	▼	◇
Customer Requirements (Explicit and Implicit) \ Functional Requirements	Motor power (W)	Material costs ($)	Material weight (lb)	Strength to turn on (N)	Bowl size (cups)	Height (inches)	Width (inches)	Length (inches)	Blade size & number
Large capacity					●				
Lightweight			●						
Easy to clean					○				
Easy to use				○					
Durable									
Low cost		●							
Small size						●	●	●	

Figure 13. Relationship between customer and functional requirements.

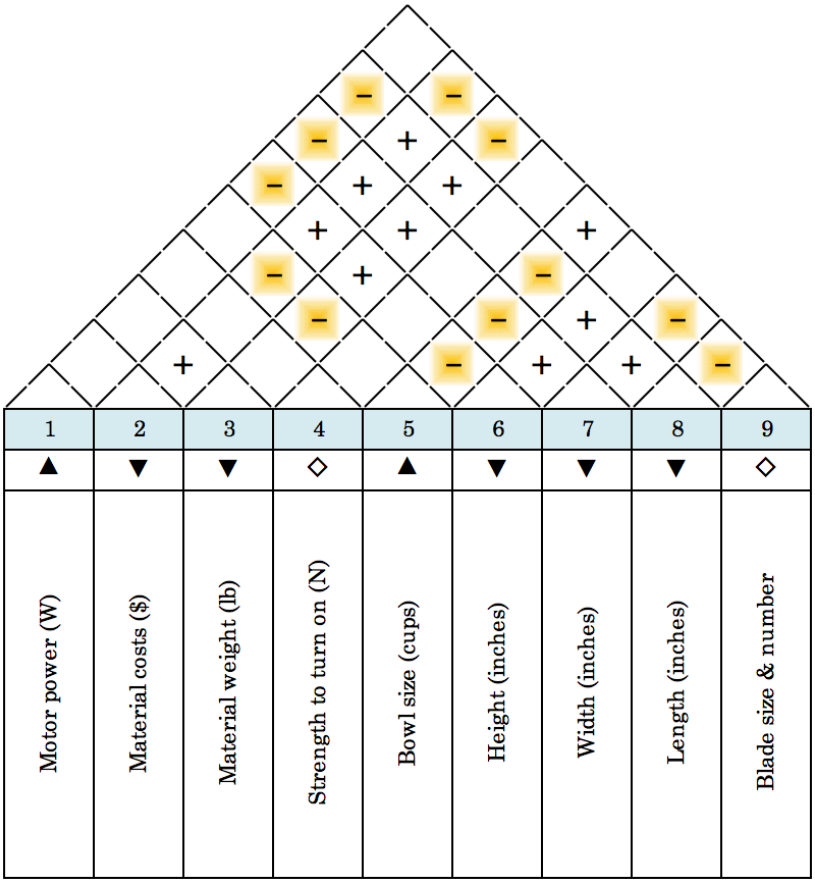


Figure 14. Relationship among functional requirements.

Finally, the aim of this is to obtain a relative importance of each of the features of the product, in order to know which of them are more relevant when trying to re-design it and improve it. Hence, this is an implement to guide a possible redesign of the product. The obtained results were the following:

Column #	1	2	3	4	5	6	7	8	9
Direction of Improvement	▲	▼	▼	◇	▲	▼	▼	▼	◇
Functional Requirements	Motor power (W)	Material costs ($)	Material weight (lb)	Strength to turn on (N)	Bowl size (cups)	Height (inches)	Width (inches)	Length (inches)	Blade size & number
Target	200	4	1	0	3	5	5	5	4
Max Relationship		9	9	3	9	9	9	9	
Technical Importance Rating	0	173,1	103,8	57,69	126,9	103,8	103,8	103,8	0
Relative Weight	0%	22%	13%	7%	16%	13%	13%	13%	0%
Weight Chart									

Figure 15. Relative importance of each feature.

The conclusion that can be obtained from all this process is that, according to client requirements, the features that would improve the most our product are related to reducing size and material costs and increasing capacity.

5. Customer requirements

		Weigth:
1.	Manipulation:	
	a. Long cable……	6
	b. Recoverable cable……..	2
	c. Does not slide while using…….	9
	d. Stable……	8
	e. Easy to dismount…….	6
	f. Not much buttons……	7
	g. Light, compact and easy to move…….....	8
2.	Durability:	
	a. Blades do not touch the inner surface……	9
	b. Minimize friction and heat……..	8
	c. Impact resistant……	6
3.	Aesthetics:	
	a. Several colors……..	6
	b. Pleasant shape……	8
	c. Not too big……	8
4.	Safety:	
	a. Protection to blades……	7
	b. Does not get too hot……...	5
5.	Effectiveness:	
	a. Hermetic seal……...	8
	b. Flat bowl surface, no ridges……..	7
	c. Constant velocity…….	6
	d. Same-size chunks……	6
6.	Easy to use:	
	a. Clear instructions…….	8
	b. Enough room for big chunks…….	5
	c. Not much options, detail in options…….	4
	d. Easy to pour out contents…….	6
7.	Ecology:	
	a. Does not consume a lot of electricity……..	6
	b. Eco-friendly materials…….	4

This is a list of features that customers would want the product to have. The difference between these ones and the ones in the HOQ is that, while the previous ones were measurable, the ones that are listed here are generally more subjective. The objective of this is to translate these statements into several objective values in order to complete and improve our HOQ.

To achieve this, several features were taken into account. The most important was the weight because, in order to summarize this into a few statements, it was necessary to discard the less relevant. Also, another key aspect was the possibility of turning them into measurable items. With these criteria, the results were the following:

					Column #	10	11	12	13
					Direction of Improvement	▲	▼	▲	▼
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) \ Functional Requirements	Friction coefficient with the table	Maximum temperature (ºC)	Number of colors	Electric consumption (W)
8	■	15%	4	9	Stability	●			
9	■	12%	3	9	Does not get too hot		●		○
10	■	15%	4	3	Aesthetics			○	
11	▮	8%	2	9	Ecology		○		●

Figure 16. New statements in the HOQ.

The additional customer requirements were summarized into four new factors: stability, aesthetics, ecology and the fact that the item does not get too hot while using. For that purpose, it was necessary to introduce some new design features as well, which are:

- Friction coefficient with the support surface, in order to improve its stability, as it avoids slipping while using.
- Maximum temperature, as if it is too much it can be dangerous and also deteriorate the machine.
- Number of available colors, as the possibility of choosing will make the customer more satisfied with the product aesthetics.
- Electric consumption, which is in conflict with the motor power. Reducing this value would make the product more efficient.

6. Improved House of Quality

After summarizing the new list of customer requirements and adding them to the HOQ, this is the resulting matrix that we obtained.

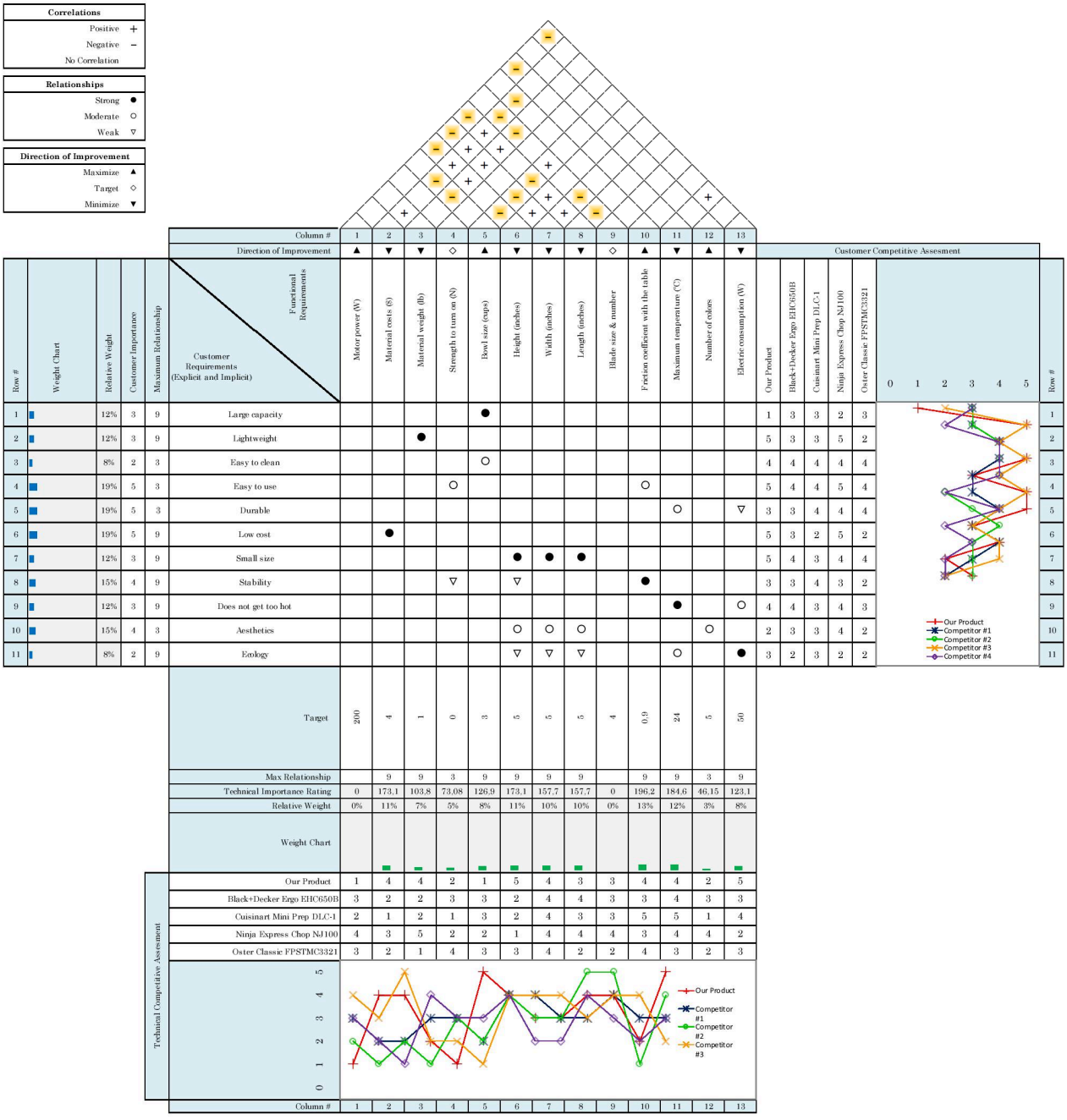


Figure 17. New House of Quality.

First of all, Figure 18 shows the new relative weight acquired by each of the customer requirements after the addition of the four that were obtained from the subjective demands that were analyzed on the previous point. Then, the evaluation and comparative of those new requirements is represented in the next matrix.

Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit)
1		12%	3	9	Large capacity
2		12%	3	9	Lightweight
3		8%	2	3	Easy to clean
4		19%	5	3	Easy to use
5		19%	5	3	Durable
6		19%	5	9	Low cost
7		12%	3	9	Small size
8		15%	4	9	Stability
9		12%	3	9	Does not get too hot
10		15%	4	3	Aesthetics
11		8%	2	9	Ecology

Figure 18. New relative weights of the customer requirements.

Customer Requirements (Explicit and Implicit)	Our Product	Black+Decker Ergo EHC650B	Cuisinart Mini Prep DLC-1	Ninja Express Chop NJ100	Oster Classic FPSTMC3321
Stability	3	3	4	3	2
Does not get too hot	4	4	3	4	3
Aesthetics	2	3	3	4	2
Ecology	3	2	3	2	2

Figure 19. Evaluation of the new customer requirements.

Secondly, on Figure 20 it is represented the evaluation and comparative of the product features that were added to the matrix to satisfy the new requirements.

Column #	10	11	12	13
Direction of Improvement	▲	▼	▲	▼
Functional Requirements	Friction coefficient with the table	Maximum temperature (°C)	Number of colors	Electric consumption (W)
Our Product	4	4	2	5
Black+Decker Ergo EHC650B	3	4	3	3
Cuisinart Mini Prep DLC-1	5	5	1	4
Ninja Express Chop NJ100	3	4	4	2
Oster Classic FPSTMC3321	4	3	2	3

Figure 20. Evaluation and comparative of the new functional requirements.

Apart from this, Figure 21 and 22 represent the new matrix relationships. The first one is the one that relates customer requirements and product features, and the second compares the functional requirements with each other.

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13
Direction of Improvement	▲	▼	▼	◇	▲	▼	▼	▼	◇	▲	▼	▲	▼
Functional Requirements / Customer Requirements (Explicit and Implicit)	Motor power (W)	Material costs ($)	Material weight (lb)	Strength to turn on (N)	Bowl size (cups)	Height (inches)	Width (inches)	Length (inches)	Blade size & number	Friction coefficient with the table	Maximum temperature (°C)	Number of colors	Electric consumption (W)
Large capacity					●								
Lightweight			●										
Easy to clean					○								
Easy to use				○						○			
Durable											○		▽
Low cost		●											
Small size						●	●	●					
Stability				▽		▽				●			
Does not get too hot											●		○
Aesthetics						○	○	○				○	
Ecology						▽	▽	▽			○		●

Figure 21. Relationships among all the requirements of the product.

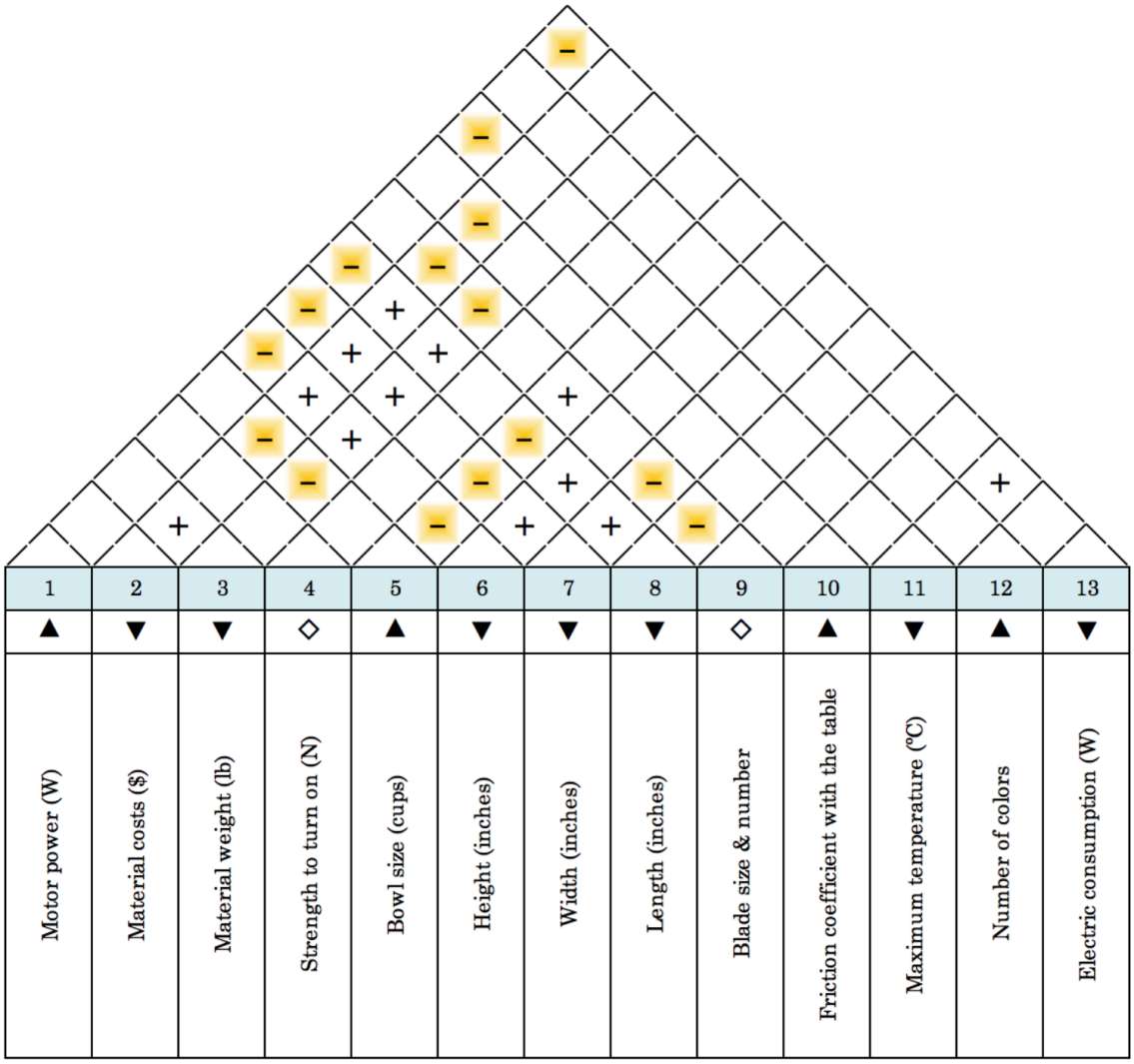


Figure 22. Positive and negative relationships among product features.

Finally, after introducing all those relationships, the results that were obtained were the following. They will be commented on the next point.

1	2	3	4	5	6	7	8	9	10	11	12	13
▲	▼	▼	◇	▲	▼	▼	▼	◇	▲	▼	▲	▼
Motor power (W)	Material costs ($)	Material weight (lb)	Strength to turn on (N)	Bowl size (cups)	Height (inches)	Width (inches)	Length (inches)	Blade size & number	Friction coefficient with the table	Maximum temperature (°C)	Number of colors	Electric consumption (W)
200	4	1	0	3	5	5	5	4	0,9	24	5	50
	9	9	3	9	9	9	9		9	9	3	9
0	173,077	103,846	73,0769	126,923	173,077	157,692	157,692	0	196,154	184,615	46,1538	123,077
0%	11%	7%	5%	8%	11%	10%	10%	0%	13%	12%	3%	8%

Figure 23. Final results of the HOQ analysis.

7. Areas of improvement

Analyzing the conclusions of the House of Quality, it can be inferred that there are four main points to modify in order to satisfy the customer requirements. Those points are the following:

- Material costs: This would not be very easy, as the materials that the machine is made of are quite cheap already. However, this could be done by searching plastics with similar properties and with a lower price. A good resource for this search is the program CES Edupack, which is a highly useful tool for browsing material properties. In order to find useful results, some constraints are necessary.

  First, there is a need to make sure that all materials are thermoplastics, since they are the only ones that allow re-grind. This technique will minimize the scrap rate, as it consists on reusing the material that is left over in the molding of other parts, so it will help to save big amounts of money in production. Also, it is necessary to make sure that the mechanical properties of the new material are similar to the previous one, which had a Young's modulus of around 1.5 GPa and a yield strength of 34 MPa, approximately. The constraints to ensure alike properties will be a minimum Young's modulus of 1 GPa and a minimum yield strength of 25 MPa. This reduces the list of possible components to 449 different thermoplastics. These materials have to be filtered in order to obtain a final result. Figure 24 represents a graph where the plastics are plotted in function of their price ($/kg) and their density ($kg/m^3$).

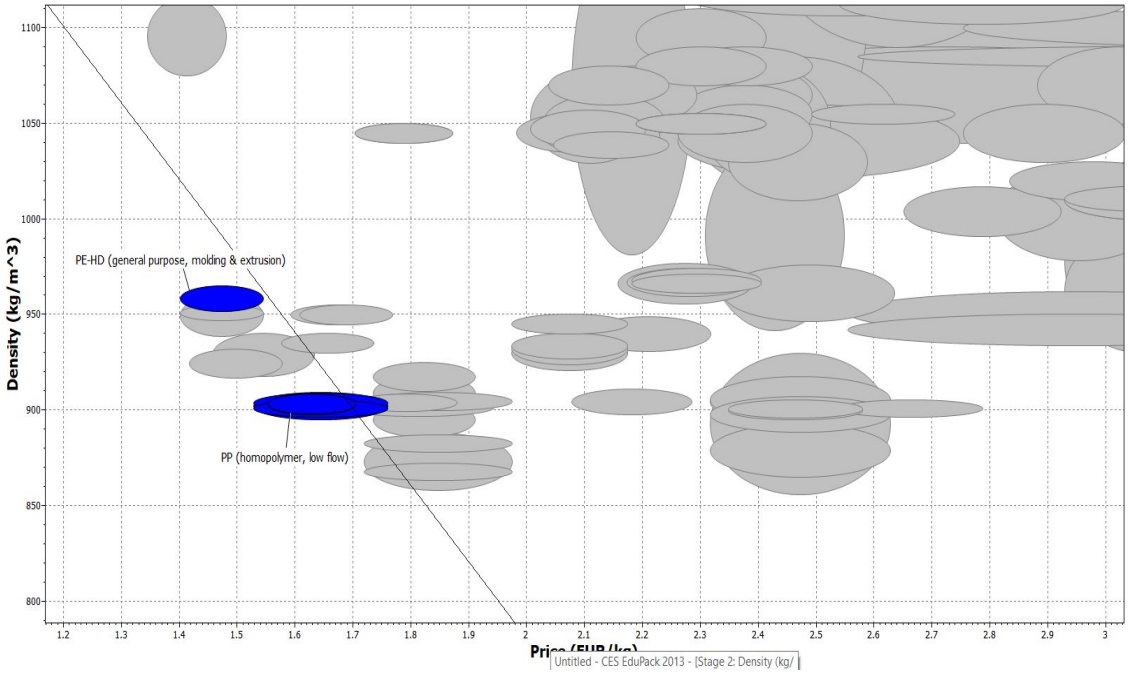


Figure 24. Plot of the materials in function of their price and their density (from CES Edupack).

This plot limits the price and the density to suitable values for the product. There has been selected a maximum density of 1100 kg/m^3 and a maximum price of 3 $/kg. Also, there is a dividing line that was made to focus on the goods on the bottom left corner, as the objective is to minimize both properties. This limits the options to 6 materials, 5 of which are different kinds of polypropylene, and the other is a high density polyethylene.

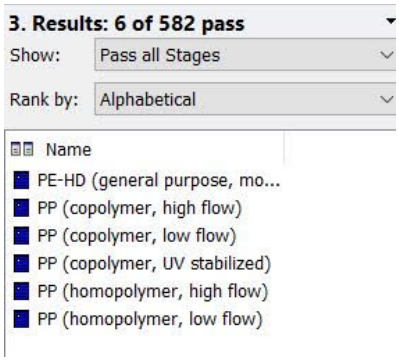


Figure 25. Material options after the second screen.

In order to do a third screen and get a final result, this six materials will be plotted function of the product of both properties, so that the resulting value would be the price per unit of volume. The chosen material will be the one that has the lowest value of that product, as it will make the new parts of the product be as cheap as possible.

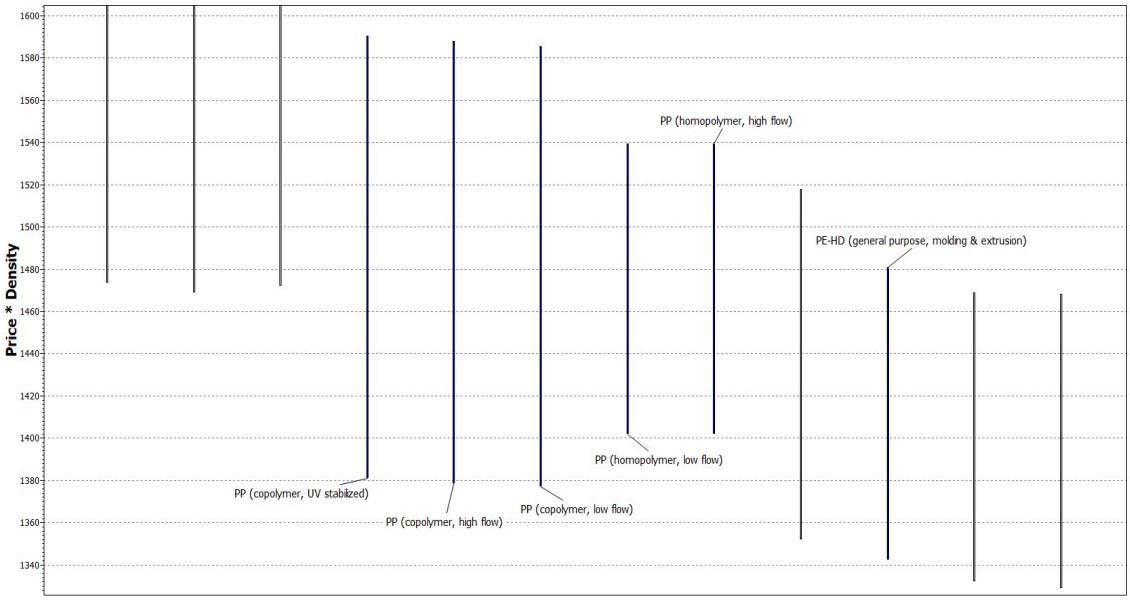


Figure 26. Plot of the materials in function of their price per unit of volume ($/m³).

Consequently, the new product will be made of high density polyethylene (PE-HD), instead of the current polypropylene.

	Polypropilene	*PE-HD*
Price (€/kg)	1.55 – 1.7	1.4 – 1.54
Density (kg/m³)	899 – 908	952 – 965
Young's modulus (GPa)	1.34 – 1.59	1.07 – 1.09
Yield strength (MPa)	32.9 – 36.4	26.2 – 31
Tensile strength (MPa)	33 – 42.9	22.1 – 31
Vickers hardness (HV)	10.1 – 10.6	7.9 – 9.9

Table 3. Comparison of the properties of both materials according to CES Edupack.

As it can be seen in Table 3, although those values are slightly lower on polyethylene than on polypropylene, this cost reduction can be carried out without compromising the mechanical properties of the product.

Another way to reducing the amount of money spent on materials is diminishing the quantity, by simplifying complex shapes and eliminating or combining parts that are not strictly necessary.

Finally, another thing that can be done is modifying the manufacturing methods. In injection molding, there are two different kind of "runners", which are the

channels that conduct the plastic into the mold cavities: hot and cold. While cold runners perform at ambient temperature, hot runners are heated such that plastic flows more uniformly. Owing to this, they need less diameter than cold ones, so less plastic has to be shot in each cycle. Also, they is more appropriated for complex shapes with less error margin in the flow, as an unequal cooling can hinder the plastic flow to the mold cavities. All this makes them increase productivity and speed of manufacturing. The only drawback is that the initial investment in machinery would be bigger, as tooling is more complex that for cold runners.

- Height: One of the main objectives of this re-design process was to reduce the size of the product, since its smallness is one of its most attractive features. Furthermore, the effort will be focused on lowering the height, as this would also provide more stability. Bearing this in mind, it will be necessary to regard how to relocate the internal parts in order to make the device less tall. This may imply changing the motor or its position, reducing the thickness of some of the plates or maybe eliminate several pieces of material. The main constraint that will be found in this aspect is the height of the motor, which is 7.5 centimeters tall, including the gear that is connected to its shaft. Hence, this will be the minimum height of the device, at least theoretically, as some empty space needs to be left over the motor for the cabling.

- Friction coefficient with the support surface: It is necessary to maximize this aspect in order to achieve greater stability and therefore a more comfortable handling. With this objective, a new material can be searched for the four stoppers that support the structure, following the criteria of cost reduction and increase of the friction coefficient with the support surface.

- Maximum temperature: Although this product does not get too hot when using, minimizing this aspect will make it safer and more comfortable to use. This can be achieved either by changing the materials or by reducing the friction between the internal parts of the mechanism, modifying its shape or simply greasing them.

8. Product Design Specification

A Product Design Specification (PDS) is a statement of how a design is going to be done, what its objective is and to what extent it will meet the previously established requirements.

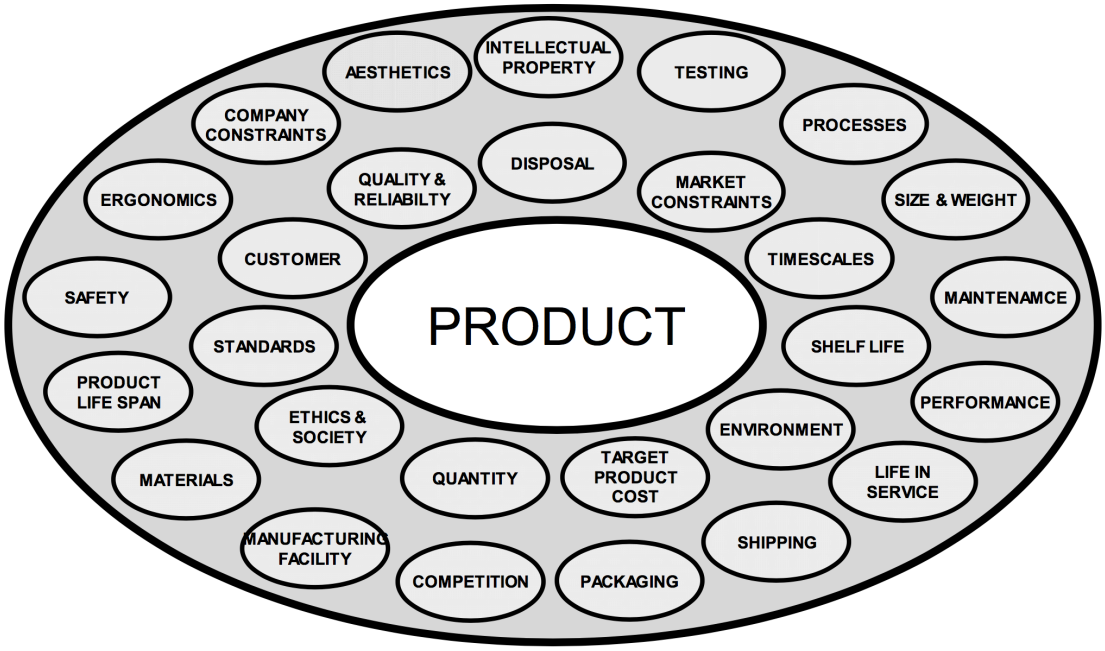


Figure 27. Standard Product Design Specification.

Each of those points are going to be evaluated individually in the following pages.

1. Performance:

This product is required to chop the food inside the bowl into little pieces. These pieces should have similar sizes, and the velocity of the blades should be constant.

2. Environment:

There is no danger of any part of the product reacting with the environment in any part of the production process. It is all made of metals and plastics, none of which would perish or change its properties when exposed to ambient.

3. Life in service:

The objective is that this product can last as much as possible. A reasonable target life expectancy for it could be 5-10 years, as it is a gadget made for an occasional use.

4. Maintenance:

This product does not require regular maintenance, just cleaning the outside parts (bowl, lid and blades), which can be done in the dishwasher.

5. Target product cost:

The objective is to minimize cost as much as possible. Some parts may be combined and some materials might be superseded in order to reduce this cypher.

6. Availability of components:

The outside parts will be manufactured by the company, so there is no need to find them in a third party. Inside, there are some parts that need to be purchased, which will be detailed on point 9. Those parts are quite common and relatively easy to find or replace.

7. Packaging:

It is necessary to package the product. It should be in a box that does not increase too much its volume, but that can protect it enough from impact and external loads before it is opened.

8. Shipping:

It can be easily transported, as it is not heavy or too fragile. Nowadays it is sold in the USA, Canada and Mexico. However, exporting it to other continents does not seem to be worthy, as it would increase significantly the cost of the product, which is one of the main features that makes it highlight among its competitors.

9. Quantity:

The objective would be a high volume production. The largest the production, the cheapest the manufacturing costs and the product price. As it has been seen before, there is a high demand, so this would not be a problem. Additionally, the company has several factories around the country that can take this task successfully.

10. Manufacturing facilities:

Hamilton Beach Brands has several factories in the USA, Canada and Mexico that are exclusively dedicated to the manufacturing of household appliances, so it would not be necessary to build or rent new facilities.

11. Size and weight:

The main (and obvious) restriction is that it must fit properly in a kitchen, without taking much space and being easily movable by a single person. Within those limits, it should

be as little and light as possible, as it is supposed to be simpler and smaller than its competitors. Also, as it is a complementary appliance, since its function is not a dairy necessity, it should leave room in the kitchen for other useful devices. Obviously, its size or weight will not restrict its transportation or access to certain places.

12. Aesthetics and finish:

This is always an important aspect, as it gives first impressions to the customers. Its finish should be modern and there should be a wide range of discrete and elegant colors so customers can choose the one that fits better in their kitchens. Since it might be kept exposed to sight, aesthetics are important because it can become part of a kitchen's decor.

13. Materials:

The main restriction of the materials to use are their costs. Plastic is a good option for most of its parts, as it is cheap and easy to manufacture without much shape restrictions. As it is designed for food processing, it is crucial that none of the materials are toxic, especially those that make up the bowl and the blades.

14. Product life span:

Nowadays, they do not exist any other appliances that can play this function automatically, so it is difficult to imagine when can this product be substituted. Hence, this product must be marketable for a long time.

15. Standards and specifications:

This kind of products are regulated by the ANSI standard UL 982, which is the Standard for Motor-Operated Household Food Preparing Machines. This standard applies to motor-operated food preparing appliances that are intended to be used for short periods of time, resulting in less than 100 hours per year. It does not cover aspects such as sanitation, contamination or noise. Those features are regulated by ASME F2.1, which is the Standard for Food, Drug and Beverage Equipment.

16. Ergonomics:

The product is very comfortable and easy to use, so it would rarely be in conflict with users' physiological or anatomical characteristics.

17. Quality and reliability:

It is a product that is meant to be used occasionally and for short periods of time, so it is predictable that it can last for several years until failure. The expected failure could be a wear on the cables, the failure of one of the inside parts (especially the gears), and a failure of the motor. They could all be replaced, but it would probably not worth, as not everyone would be able to do it and it would not be much more expensive to buy another device. Another part that could be damaged with usage and that would be a good option to give the possibility of replacement is the blade.

18. Shelf life:

This product does not have perishable components, so it would not deteriorate if it had to be kept a big period stored. Consequently, it does not have any specific requirements for long storage times.

19. Processes:

Most of the pieces are plastic-injection-molded. There are also some metal parts that can be manufactured by forging and machining. The rest would be purchased.

20. Testing:

Each electrical part has to be tested separately before assembling, in order to check that they work correctly and at the desired power level, and to reject the ones that do not work appropriately. Also, operators must check every product when all the parts are assembled, and discard those that do not work correctly, so they can be reassembled.

21. Safety:

The most feasible accident would be related to the blades, that are prone to make harm if touched. However, if it is used with the bowl closed, as it is meant to be, it is impossible to be in contact with the blades, so this danger would exist when the device is not working, most probably while cleaning. It could also be dangerous to have a dead short, but the circuit is supposed to be well isolated.

22. Company constraints:

Hamilton Beach Brands is specialized in kitchen appliances of all kinds, so it will fit in perfectly with current company practice. It will not produce any constraints on production or personnel.

23. Market constraints:

As it has been said before, one of the main qualities that this product has to highlight in the market is its low price, which would increase considerably if it was exported to other continents. According to this, the sales may be restricted to North America.

24. Intellectual property:

It was first patented in 1994 by Jean Pierre Busquets and Jean Pierre Trocherie, in the application FR2725383A1. This patent was assigned to the company Moulinex SA, but later it expired. Now, it is included in the food processor patent WO2008047106A1, which was registered by Adrienne Grant in 2007.

25. Ethics and society:

The liability of this company resides on what they can do to avoid a damaging use of the product. They have to make sure that it is impossible that the food that is being processed gets contaminated, which can have dangerous consequences on users. Hence, they have to strictly follow the standards mentioned above. Also, the blades can be used to make harm, so if there is any possibility to avoid that it must be considered.

26. Customers:

The range of clients of this item can be very wide. Due to its low price, everyone can afford to buy it. However, since it is not a necessary appliance, low social classes may be less interested on buying it. Also, the highest classes would probably buy a more luxurious similar product. Taking all this into account, it can be summarized that this product can be directed to the whole public, but most of its buyers will belong to the medium class, which is also the most numerous. Hence, it should probably be addressed to those houses.

27. Timescales:

It will not take too long to manufacture this product. There are a lot of parts that are purchased, so they will not need to be produced by the company. The rest of them are made by injection molding, forging or machining, all of which are very quick processes. The assembly of this product is also quite simple. Furthermore, as it will only be sold in North America, the transportation, which will probably be by road or train, will not take more than 2-3 days at most.

28. Competition:

There are a lot of competitors for this product. The main ones have been analyzed on point 2. On that point, we saw that our product did not have the best quality, but it had some features to highlight in the food chopper submarket, which were its low price and its small size. In the market of food-processing devices, food choppers can be threatened by multifunction processors, some of which can play the same function as choppers. The advantage of those products against choppers is that they allow to have less kitchen appliances, but on the other hand choppers are simpler and easier to manipulate.

9. DFA Analysis

In Table 3 there is a bill of materials of the product, which is the same as in point 1, but now including the material and manufacturing process of each part.

	Part	Material	Manuf. process
1	Main cover	Polypropylene (PP)	Injection molding
2	Top cover	Polypropylene (PP)	Injection molding
3	Bottom cover	Polypropylene (PP)	Injection molding
4	Gear-holding plate	ABS Plastic	Injection molding
5	Gear	ABS Plastic	Purchased
6	Shaft	Aluminum	Machining/forged
7	Motor	Aluminum	Purchased
8	Switch	ABS Plastic	Purchased
9	Torsion spring	Stainless steel	Purchased
10	Stopper	Rubber	Injection molding
11	Ring 1	Stainless steel	Purchased
12	Ring 2	ABS Plastic or stainless steel	Purchased
13	Ring 3	ABS Plastic/stainless steel	Purchased
14	Screw	Stainless steel	Purchased
15	Cable holder	ABS Plastic	Injection molding
16	Blade	Polypropylene (PP)/stainless steel	Injection molding /forged
17	Cup	ABS Plastic	Injection molding
18	Lid	ABS Plastic	Injection molding
19	Cables	Copper/plastic	Purchased

Table 4. List of materials and manufacturing processes.

Analyzing each part one by one, it was found that it was possible to combine or eliminate several parts. To identify which ones were more suitable for that, it was necessary to do a DFA analysis. For this purpose, it is helpful to answer the following questions:

1. Does a part move simultaneously with another part?

Yes. One of the gears is connected to the shaft, which is also connected to the blades. These three parts rotate with the same velocity. Almost all the rest of the parts (unless the other gear and the motor shaft) stay still. In Table 4, there is a list of the parts that do not move.

Part	Material	Manuf. process
Main cover	Polypropylene (PP)	Injection molding
Top cover	Polypropylene (PP)	Injection molding
Bottom cover	Polypropylene (PP)	Injection molding
Gear-holding plate	ABS Plastic	Injection molding
Motor	Aluminum	Purchased
Switch	ABS Plastic	Purchased
Torsion spring	Stainless steel	Purchased
Stopper	Rubber	Injection molding
Screw	Stainless steel	Purchased
Cable holder	ABS Plastic	Injection molding
Cup	ABS Plastic	Injection molding
Lid	ABS Plastic	Injection molding
Cables	Copper/plastic	Purchased

Table 5. List of the parts that do not move.

From all these materials, there were some that could not be combined or eliminated. The design of those ones that have to be purchased (motor, switch, spring, screws and cables) cannot be modified. Also, the cup and the lid have to be separate for functionality, as they have to be easily removable to clean the gadget after using.

Furthermore, it is reasonable to focus on the parts that do not move. This is because, just as it happens with the cup and the lid, the blades also need to be taken out of the machine when cleaning. This brings up to the question whether the gear and the shaft can be combined in a single part. The answer is no, since it would greatly complicate the assembly of the pieces.

2. Can the part be the same material as this other part?

After this first screen, the components that we are still considering to combine are the following:

Part	Material	Manuf. process
Main cover	Polypropylene (PP)	Injection molding
Top cover	Polypropylene (PP)	Injection molding
Bottom cover	Polypropylene (PP)	Injection molding
Gear-holding plate	ABS Plastic	Injection molding
Stopper	Rubber	Injection molding
Cable holder	ABS Plastic	Injection molding

Table 6. Materials that do not move and can be modified.

Unless the stoppers, all of them are made of injection-molded plastic. The objective, which seems possible, is to see whether they can all be made with the same material, so

they can be combined. As it has been said before, the stoppers are the supporting points of the machine, in which we want to maximize the friction coefficient so that it will not slip, so they definitely cannot be made of the same material as the other parts.

3. Can the manufacturing method and tolerance be the same for these parts?

Yes, since all of them can be made by injection molding. Therefore, the Theoretical Minimum Number of Parts in the assembly will be 16, since there were 19 elements and we are removing three, as those five components that we are combining will result at least in two new pieces.

The idea is to combine the parts in the following way. In the top part, there is a cavity where there are only a switch and a torsion spring. The switch will be assembled in the new main case, so the top cover and the four screws that used to join it to the base will disappear. It will be necessary to think of a new mechanism to operate the switch, for which the old spring will be used if possible.

Also, inside the base, there is a middle plate where the motor and the gears are assembled. It will be studied how this plate can be suppressed. Most probably, it will be necessary to accommodate the case and the bottom cover so that the motor and the gears can be assembled on them. This will let us do without a whole plate and at least two of the screws.

Finally, on the plate that we are eliminating, there was a part that we called “cable holder”, that consisted of a piece of plastic that was subjected to the plate with two screws in order to fasten the wire. The objective is to create a protrusion in the case or in the bottom plate that can fulfill the same function, so that we would need one plastic part and two screws less for the assembly.

10. CAD modeling of the existing product

In order to later calculate the costs of manufacturing the existing parts that are going to be replaced, it is necessary to create a 3D model of them. The program that has been used for that purpose was Creo Parametric.

The first one is the main case, which is made of polypropylene. It is the main part of the base, to which the bowl is assembled and where the motor and the whole mechanism is contained. Its shape is going to be modified so that the motor can be assembled on it and also with the objective of reducing the volume as much as possible.

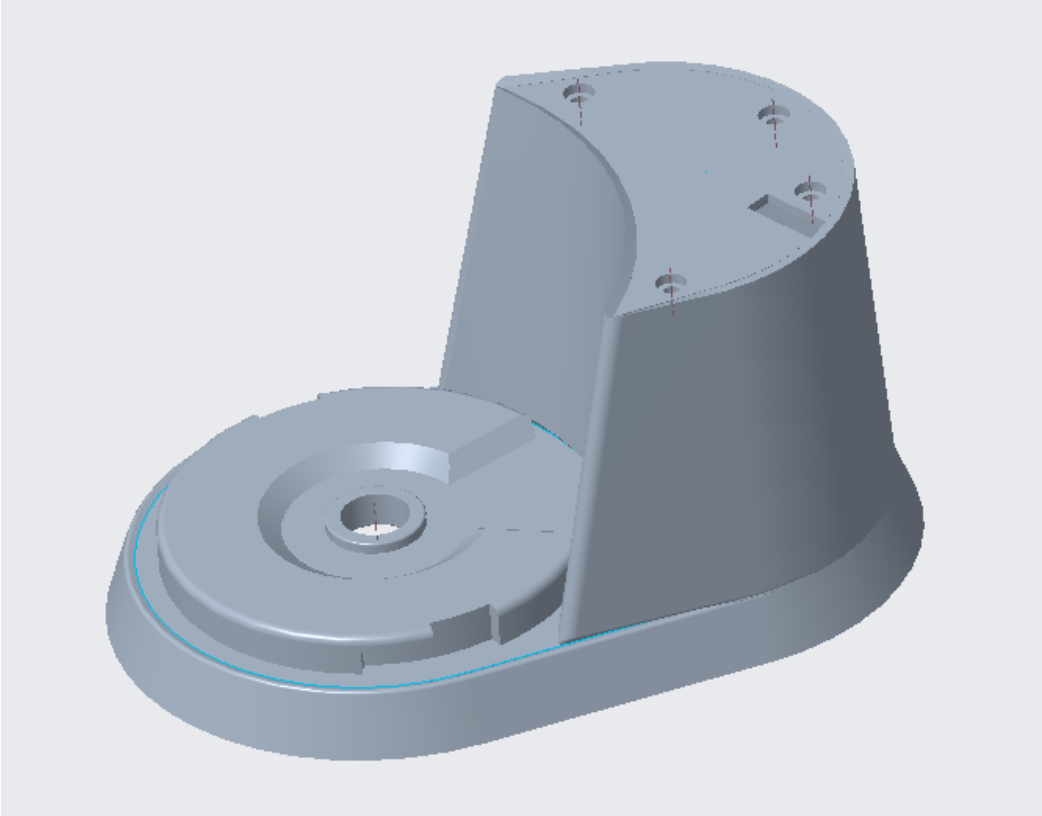


Figure 28. 3D model of the main case.

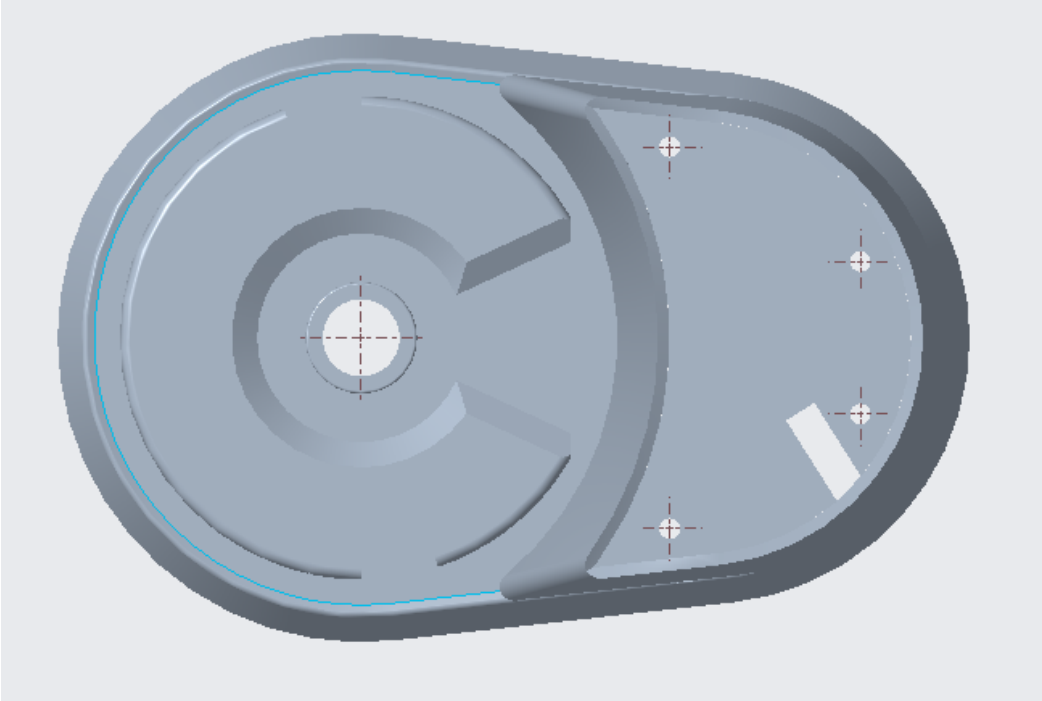


Figure 29. Top view of the main case.

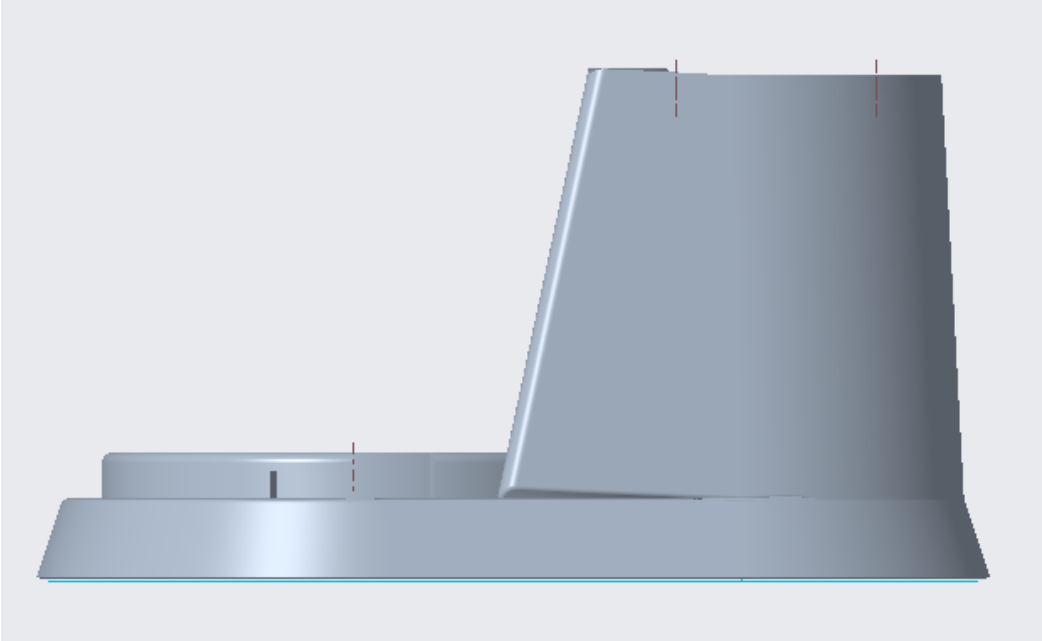


Figure 30. Side view of the main case.

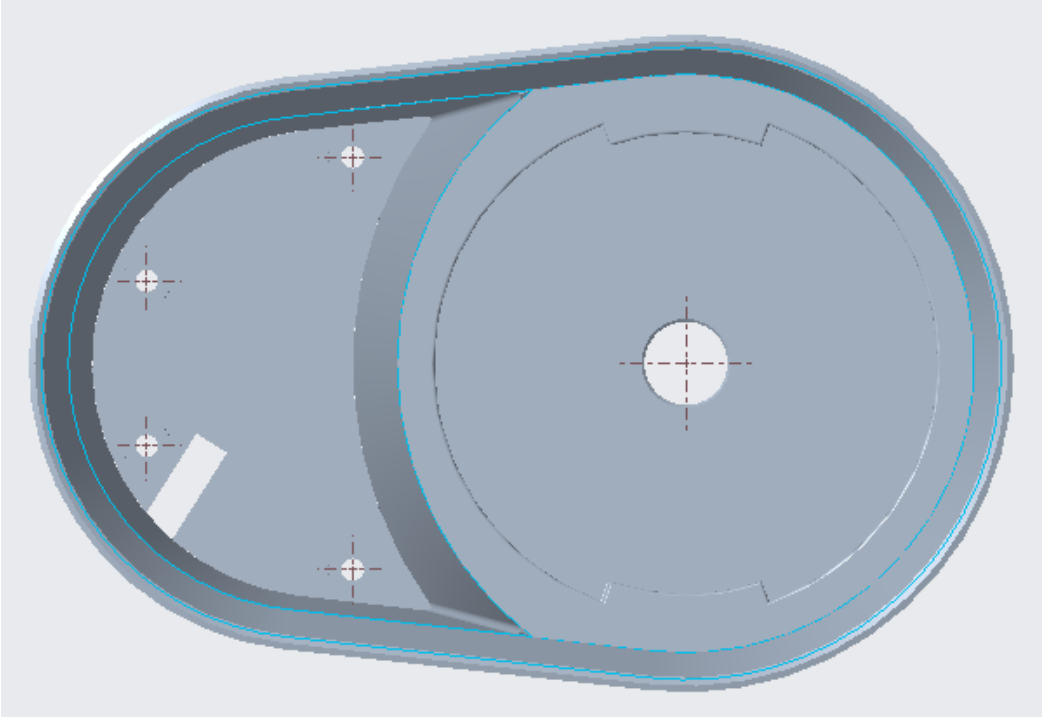


Figure 31. Bottom view of the main case.

The second one is the cover, which is assembled at the bottom of the base. It is also made of polypropylene.

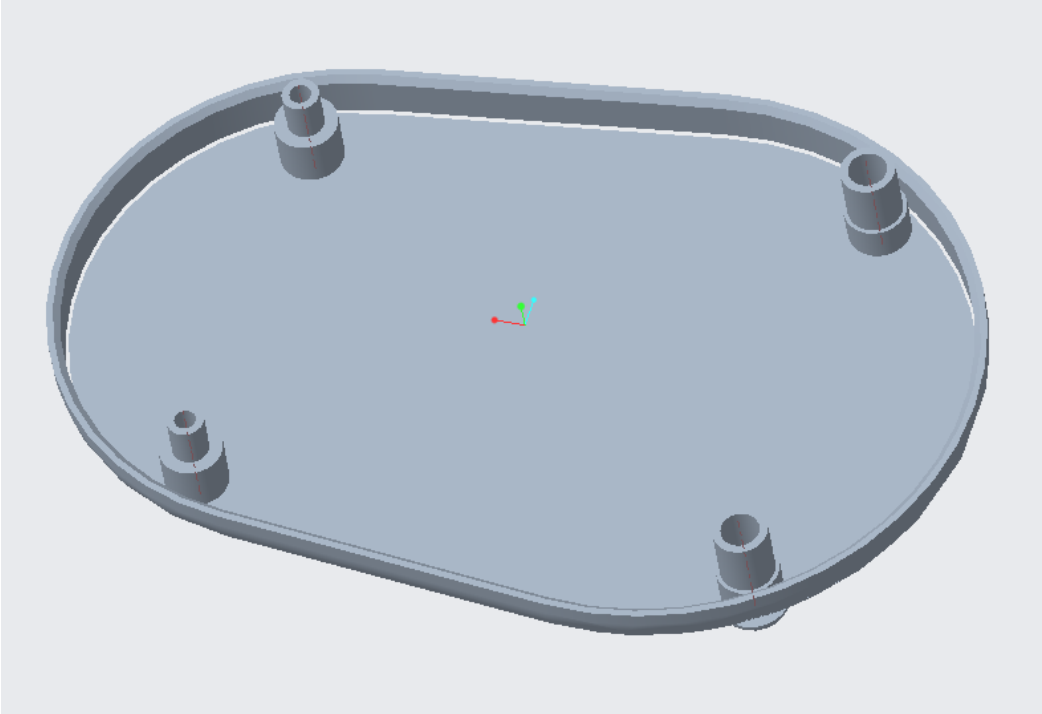


Figure 32. 3D model of the cover.

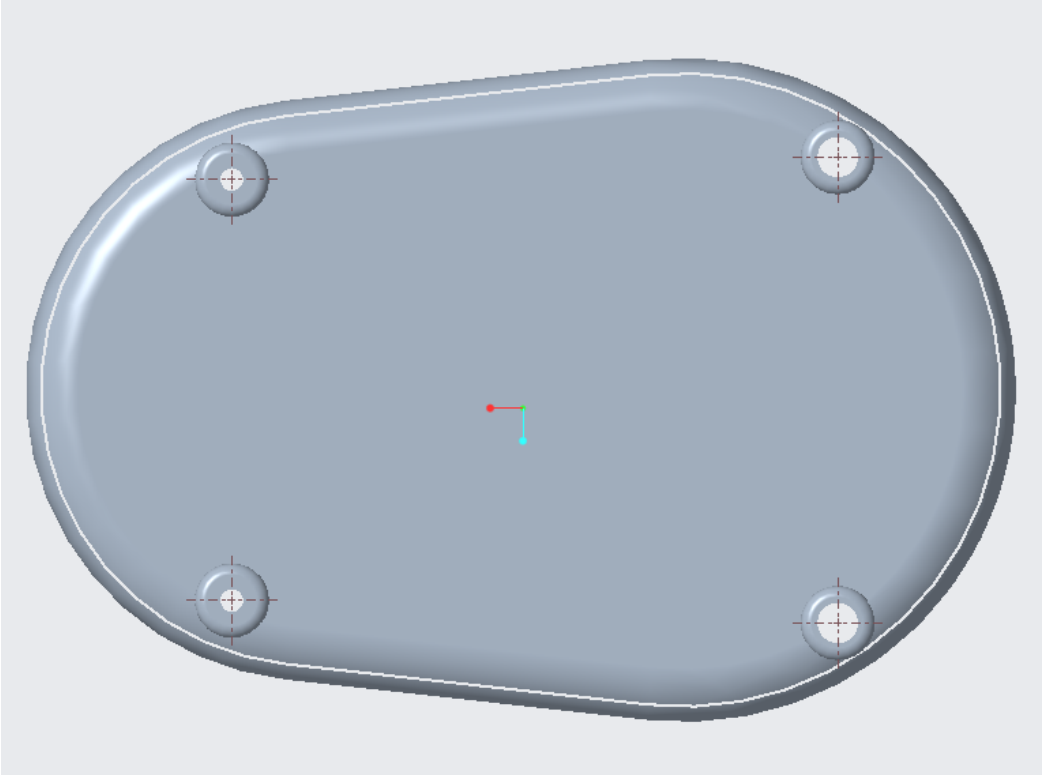


Figure 33. Bottom view of the cover.

The third part is the internal plate, which holds the motor and the three gears of the mechanism. This one is made of ABS plastic, and the objective is to remove it in order to reduce the number of plastic parts as well as the manufacturing costs and the volume of the device.

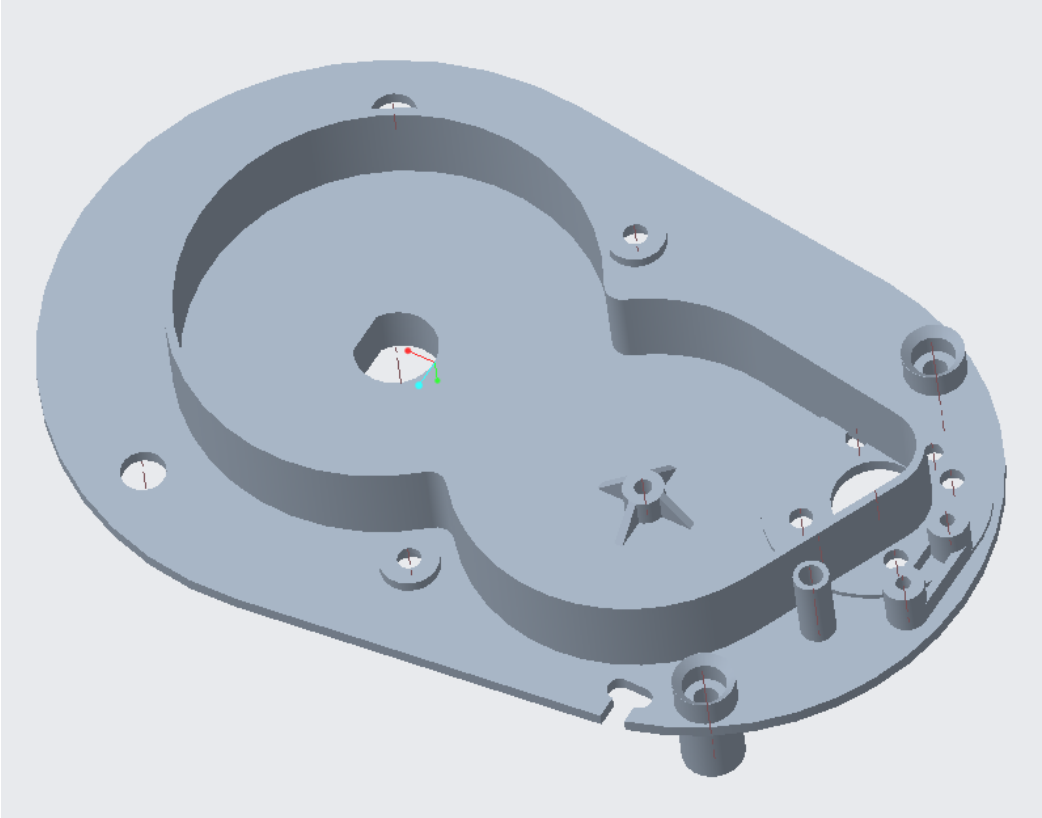


Figure 34. 3D model of the internal plate.

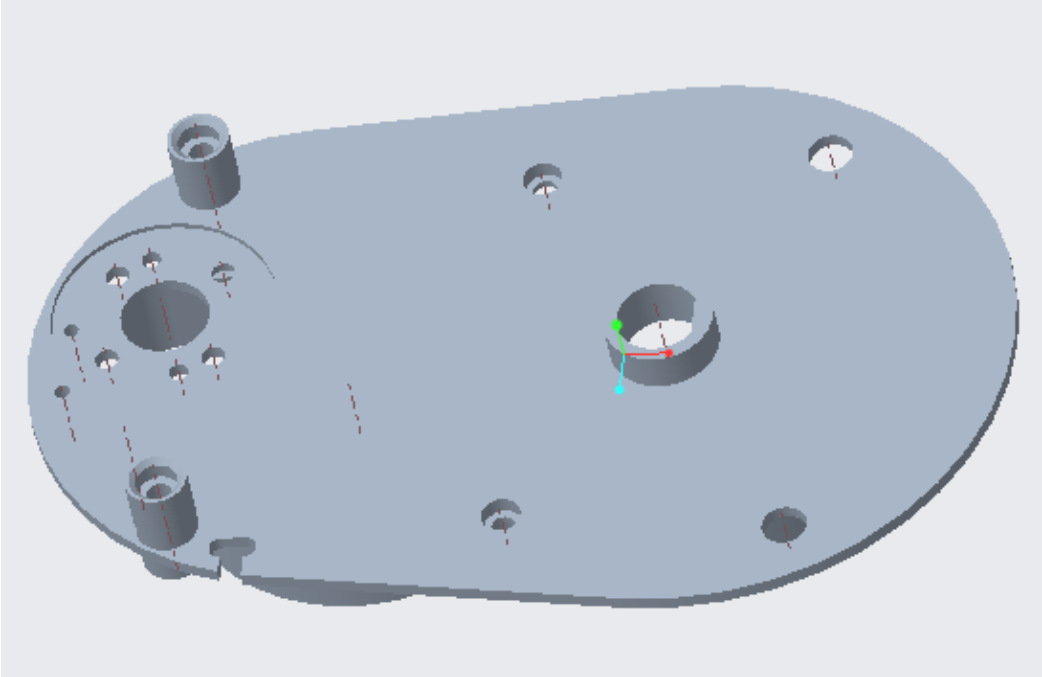


Figure 35. Top side of the internal plate.

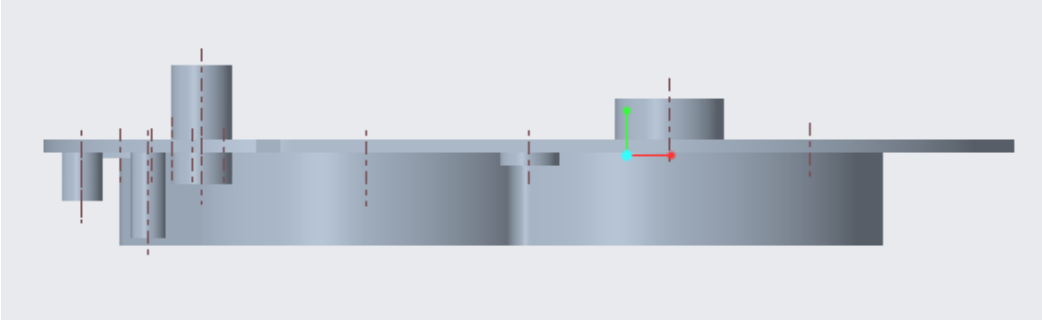


Figure 36. Side view of the internal plate.

The fourth part is the top cover, which hides a cavity where the switch is held. This switch is actuated by the lid of the bowl. When the lid is turned, it is introduced in the groove that this cover has and presses the switch. There is also a spring that makes the lid go back to its initial position.

The cover is also made of polypropylene and is fixed by four screws. The objective is to eliminate this cavity so this part and the screws can be eliminated as well.

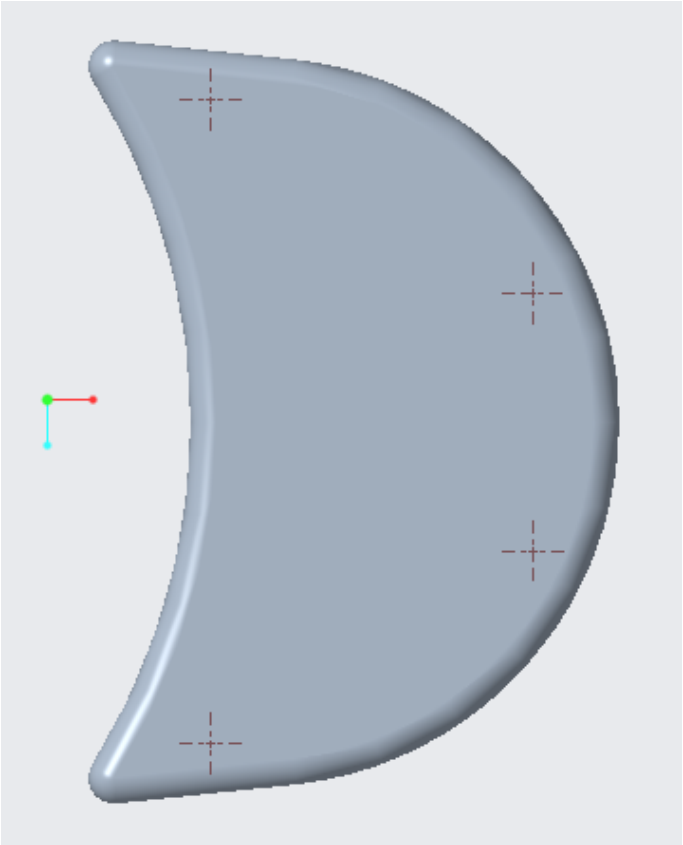


Figure 37. Top view of the cover.

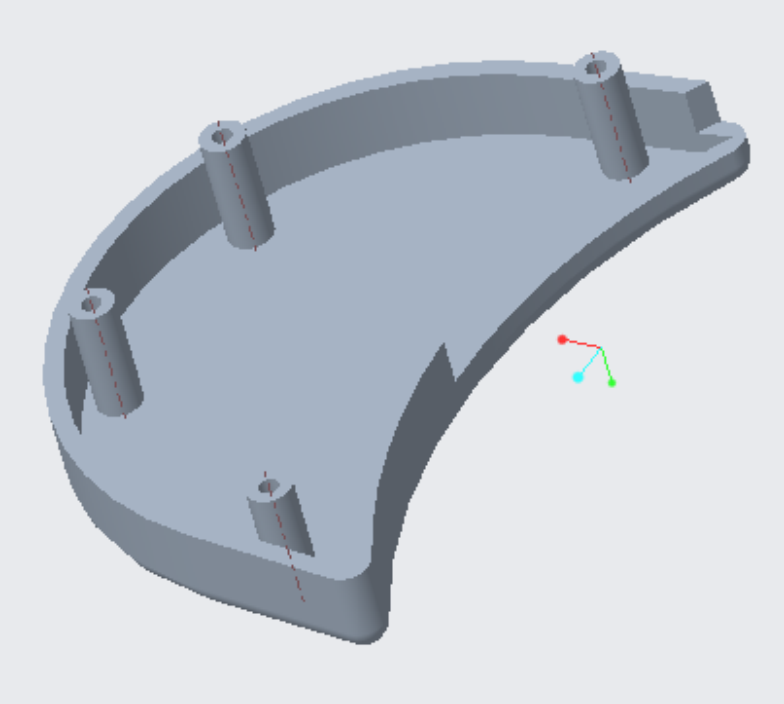


Figure 38. Bottom side of the top cover.

Lastly, there is a little part that fixes the cable to the internal plate. It is screwed to two of the threaded holes on that plate. It is also made of ABS plastic and it is also going to be removed.

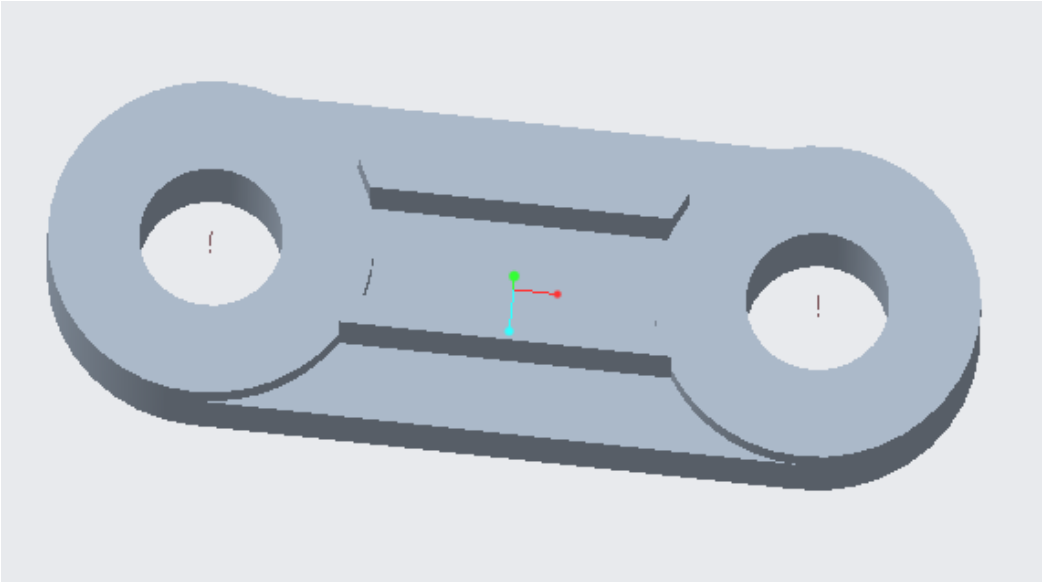


Figure 39. Top side of the cable holder.

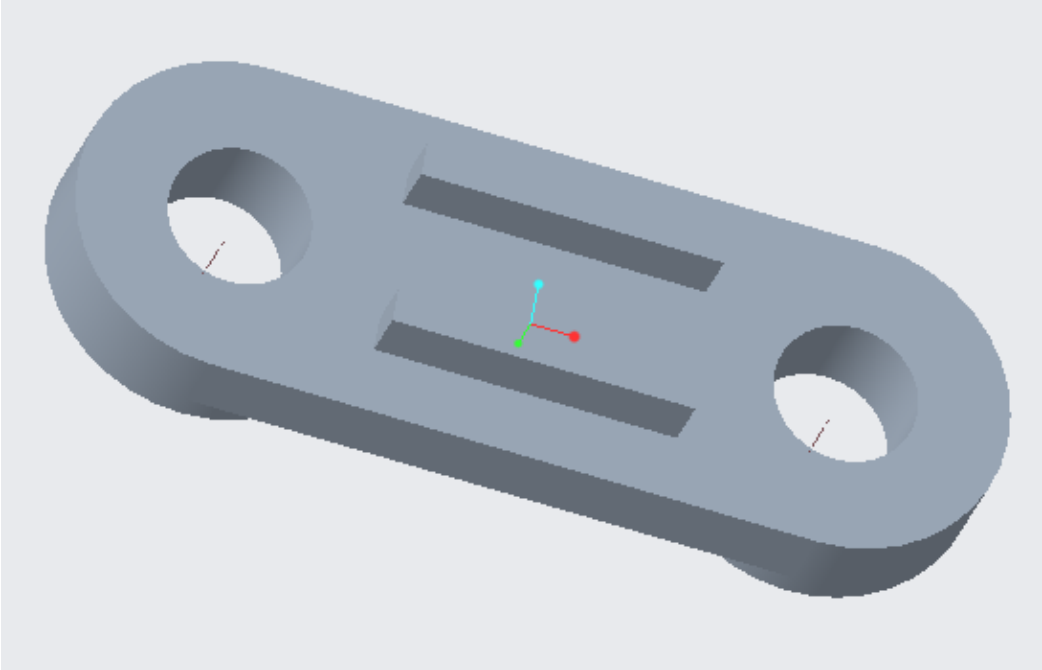


Figure 40. Bottom side of the cable holder.

Once all these parts are CAD-modeled, it is possible to make a simulation of the whole assembly so as to see how all of them are put together. As it can be appreciated in the following figures, the cable holder is screwed to the plate that holds the gears and the motor, which is also attached to the internal part of the main case. This is all covered by the bottom lid, which is also joined to the case, as well as the top cover, which is screwed to the top part.

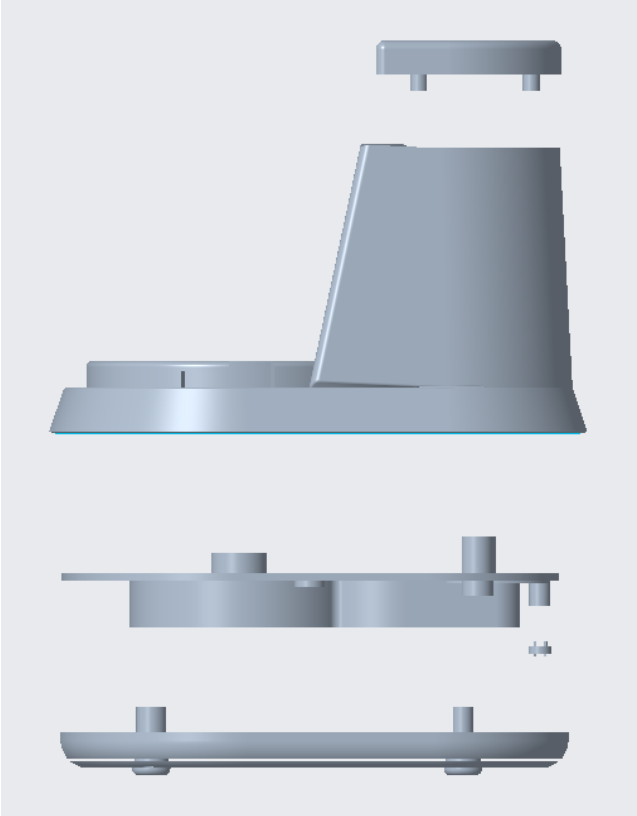


Figure 41. Representation of the assembly of the product.

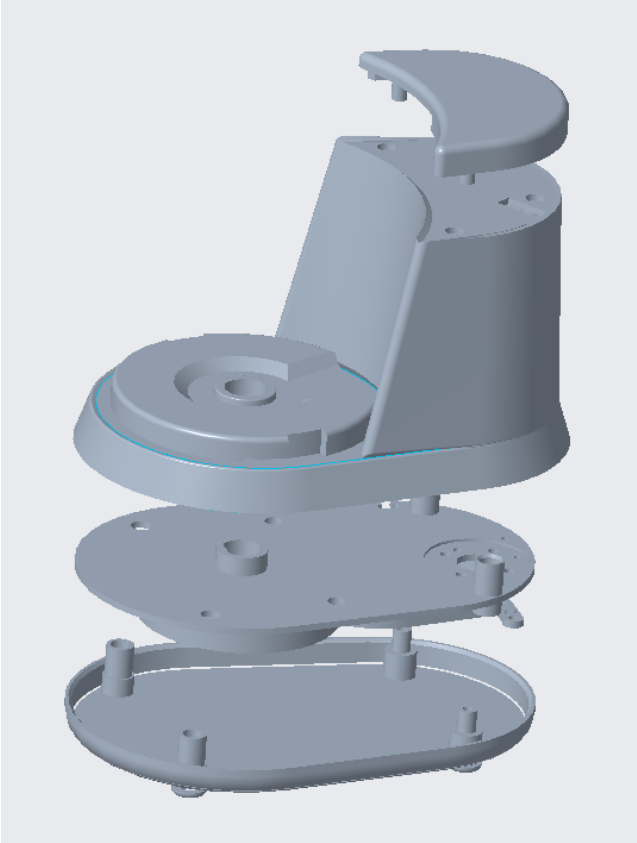
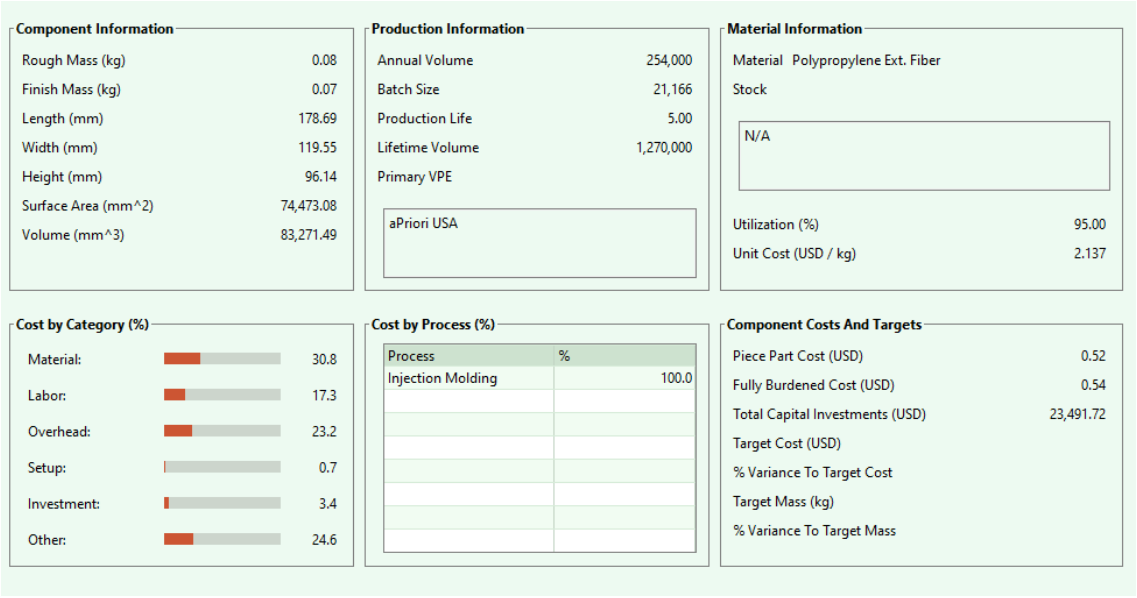


Figure 42. Another view of the assembly.

11. Manufacturing cost analysis of the existing product

After modeling all the parts under study in CAD, they can be introduced in aPriori, which is a software that makes a highly detailed simulation of the costs that the mass production of this device entails. This calculation was made for a production life of 5 years, assuming the 254,000 units per year surmised on point 2.

As all these pieces are made by injection molding, it is extremely cheap to produce them, but it is needed a big initial investment for machinery and tooling. The results obtained for the main case are the following:



Component Information

Rough Mass (kg)	0.08
Finish Mass (kg)	0.07
Length (mm)	178.69
Width (mm)	119.55
Height (mm)	96.14
Surface Area (mm^2)	74,473.08
Volume (mm^3)	83,271.49

Production Information

Annual Volume	254,000
Batch Size	21,166
Production Life	5.00
Lifetime Volume	1,270,000
Primary VPE	

aPriori USA

Material Information

Material Polypropylene Ext. Fiber

Stock

N/A

Utilization (%)	95.00
Unit Cost (USD / kg)	2.137

Cost by Category (%)

Material:	30.8
Labor:	17.3
Overhead:	23.2
Setup:	0.7
Investment:	3.4
Other:	24.6

Cost by Process (%)

Process	%
Injection Molding	100.0

Component Costs And Targets

Piece Part Cost (USD)	0.52
Fully Burdened Cost (USD)	0.54
Total Capital Investments (USD)	23,491.72
Target Cost (USD)	
% Variance To Target Cost	
Target Mass (kg)	
% Variance To Target Mass	

Figure 43. Summary of the costs information of the main case.

Variable Costs	Current (USD)
Material Cost	0.17
Labor	0.09
Direct Overhead	0.13
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.39
Period Costs	
Indirect Overhead	0.09
SG&A	0.04
Margin	0.00
Piece Part Cost	0.52
Fixed Costs	
▼ Hard Tooling (amortized)	0.02
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.02
Fully Burdened Cost	0.54
Capital Costs	
▼ Hard Tooling	23,491.72
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	23,491.72

Figure 44. Disglosed costs of the main case.

As it is shown in figures 38 and 39, manufacturing each case will cost an amount of $0.52, which, including the amortization of the $23,491.72 of initial investment, would rise up to $0.54. Now, this calculation will be repeated with the same parameters for the lower cover.

Component Information

Rough Mass (kg)	0.03
Finish Mass (kg)	0.03
Length (mm)	163.72
Width (mm)	108.24
Height (mm)	22.80
Surface Area (mm^2)	33,444.37
Volume (mm^3)	36,909.58

Production Information

Annual Volume	254,000
Batch Size	21,166
Production Life	5.00
Lifetime Volume	1,270,000
Primary VPE	

aPriori USA

Material Information

Material Polypropylene Ext. Fiber

Stock

N/A

Utilization (%)	95.00
Unit Cost (USD / kg)	2.137

Cost by Category (%)

Material:	17.3
Labor:	31.8
Overhead:	11.6
Setup:	0.6
Investment:	4.6
Other:	34.2

Cost by Process (%)

Process	%
Injection Molding	100.0

Component Costs And Targets

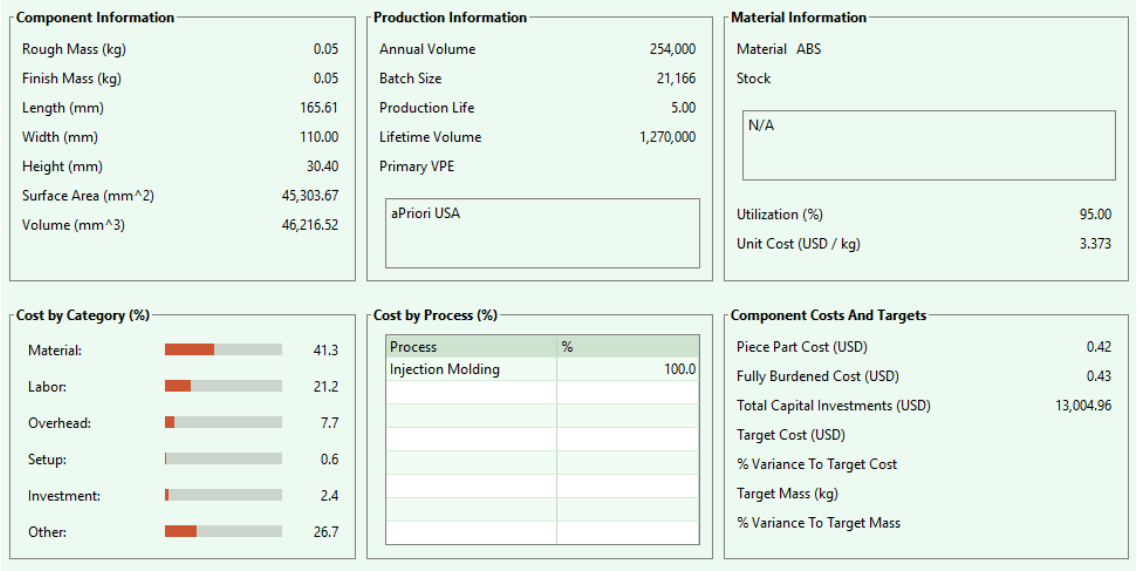
Piece Part Cost (USD)	0.41
Fully Burdened Cost (USD)	0.43
Total Capital Investments (USD)	24,675.72
Target Cost (USD)	
% Variance To Target Cost	
Target Mass (kg)	
% Variance To Target Mass	

Figure 45. Summary of the costs information of the bottom cover.

Variable Costs	Current (USD)
Material Cost	0.07
Labor	0.14
Direct Overhead	0.05
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.26
Period Costs	
Indirect Overhead	0.12
SG&A	0.03
Margin	0.00
Piece Part Cost	0.41
Fixed Costs	
▼ Hard Tooling (amortized)	0.02
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.02
Fully Burdened Cost	0.43
Capital Costs	
▼ Hard Tooling	24,675.72
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	24,675.72

Figure 46. Disglosed costs of the bottom cover.

As we can see, this part is cheaper, since less material is needed for its production. However, the investments in hard tooling are not less than for the previous piece. For this cover, the cost of manufacturing each unit is $0.41, and the machinery that would be necessary to produce them would cost to the company an amount of 24,675.72 dollars. Hence, if the amortization of the machinery is included, it would reach $0.43. The next two figures will show the simulation of the costs of the internal plate, for which the same procedure is used but with a different material. Now, ABS plastic is going to be used, which is a little more expensive than polypropylene, but has greater resistance to impact and to high temperatures.



Component Information

Rough Mass (kg)	0.05
Finish Mass (kg)	0.05
Length (mm)	165.61
Width (mm)	110.00
Height (mm)	30.40
Surface Area (mm^2)	45,303.67
Volume (mm^3)	46,216.52

Production Information

Annual Volume	254,000
Batch Size	21,166
Production Life	5.00
Lifetime Volume	1,270,000
Primary VPE	

aPriori USA

Material Information

Material ABS

Stock

N/A

Utilization (%)	95.00
Unit Cost (USD / kg)	3.373

Cost by Category (%)

Material:	41.3
Labor:	21.2
Overhead:	7.7
Setup:	0.6
Investment:	2.4
Other:	26.7

Cost by Process (%)

Process	%
Injection Molding	100.0

Component Costs And Targets

Piece Part Cost (USD)	0.42
Fully Burdened Cost (USD)	0.43
Total Capital Investments (USD)	13,004.96
Target Cost (USD)	
% Variance To Target Cost	
Target Mass (kg)	
% Variance To Target Mass	

Figure 47. Summary of the costs information of the internal plate.

Variable Costs	**Current (USD)**
Material Cost	0.18
Labor	0.09
Direct Overhead	0.03
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.31
Period Costs	
Indirect Overhead	0.08
SG&A	0.03
Margin	0.00
Piece Part Cost	0.42
Fixed Costs	
▼ Hard Tooling (amortized)	0.01
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.01
Fully Burdened Cost	0.43
Capital Costs	
▼ Hard Tooling	13,004.96
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	13,004.96

Figure 48. Disglosed costs of the internal plate.

As it has been said before, this material is more expensive than polypropylene. However, the cost of each unit of this part is $0.42, which is more or less the same as the previous one. This is because, in spite of spending more money on materials, the labor costs are

less for this part than for the cover. Also, the initial investments are quite lower, as the required amount for this machinery is 13,004.96 dollars. Adding the amortization of the hard tooling to the cost per unit, the total cost of each part will be $0.43.

The next part is the top cover, which is also made of polypropylene. This part is the smallest polypropylene part, so it will be predictably quite cheaper than the previous ones.

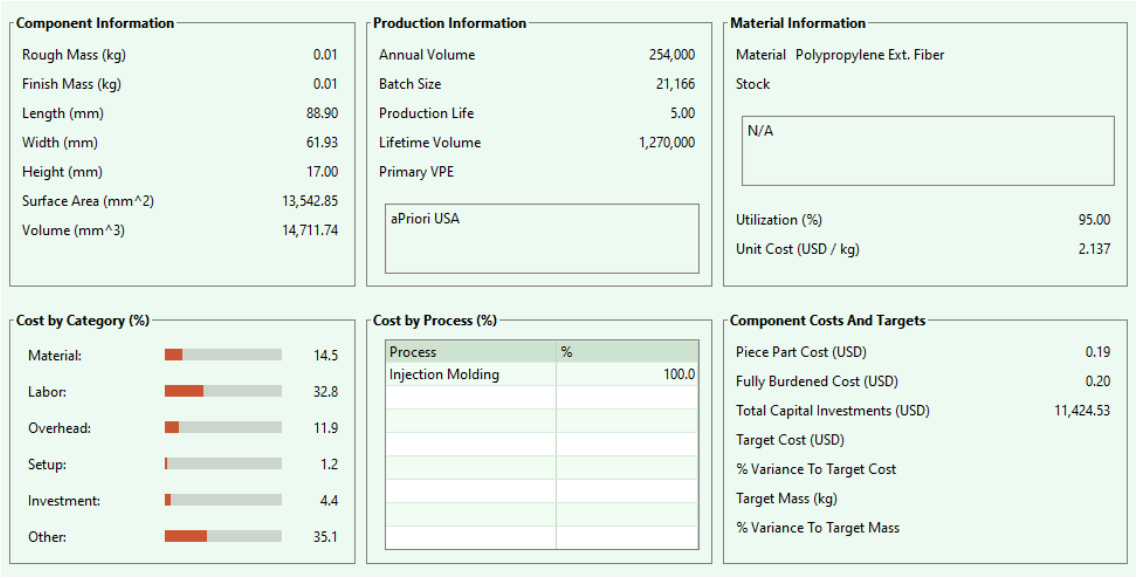


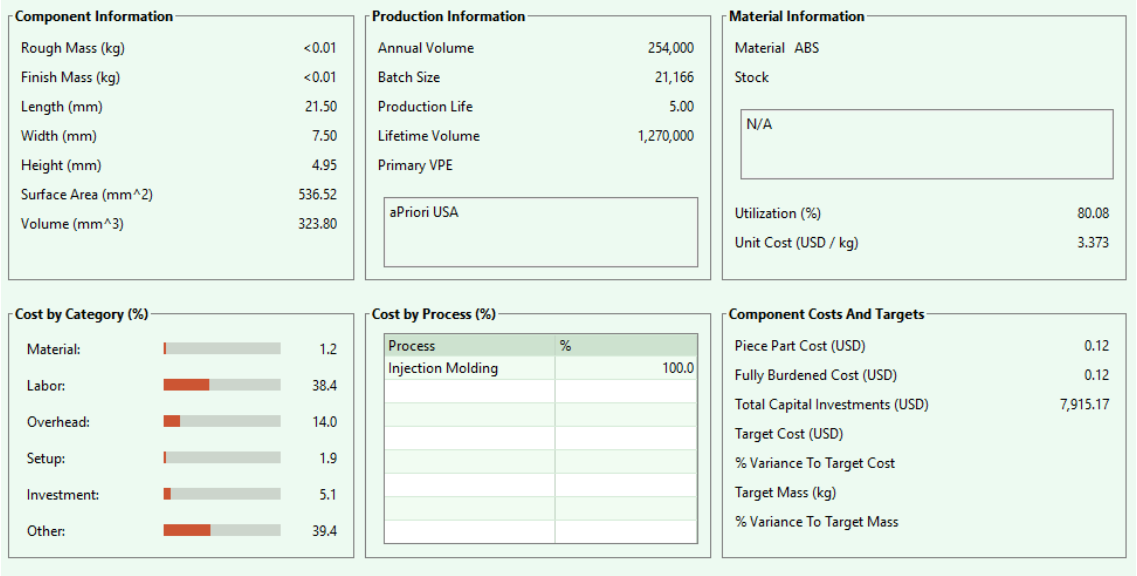
Figure 49. Summary of the costs information of the top cover.

Variable Costs	Current (USD)
Material Cost	0.03
Labor	0.07
Direct Overhead	0.02
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.12
Period Costs	
Indirect Overhead	0.06
SG&A	0.01
Margin	0.00
Piece Part Cost	0.19
Fixed Costs	
▼ Hard Tooling (amortized)	0.01
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.01
Fully Burdened Cost	0.20
Capital Costs	
▼ Hard Tooling	11,424.53
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	11,424.53

Figure 50. Disglosed costs of the top cover.

The investments on machinery for the manufacturing of this part are $11,424.53. The cover, that weights only 0.01 kg, will cost $0.19 to produce, including the costs of material, labor, … Adding the amortization of the hard tooling, the total cost of each unit will be $0.20.

Finally, the last part under study is the cable holder, which is the smallest one and is also made of ABS plastic. Due to its very little size, it will predictably be the cheapest part of interest.



Component Information

Rough Mass (kg)	<0.01
Finish Mass (kg)	<0.01
Length (mm)	21.50
Width (mm)	7.50
Height (mm)	4.95
Surface Area (mm^2)	536.52
Volume (mm^3)	323.80

Production Information

Annual Volume	254,000
Batch Size	21,166
Production Life	5.00
Lifetime Volume	1,270,000
Primary VPE	

aPriori USA

Material Information

Material ABS

Stock

N/A

Utilization (%)	80.08
Unit Cost (USD / kg)	3.373

Cost by Category (%)

Material:	1.2
Labor:	38.4
Overhead:	14.0
Setup:	1.9
Investment:	5.1
Other:	39.4

Cost by Process (%)

Process	%
Injection Molding	100.0

Component Costs And Targets

Piece Part Cost (USD)	0.12
Fully Burdened Cost (USD)	0.12
Total Capital Investments (USD)	7,915.17
Target Cost (USD)	
% Variance To Target Cost	
Target Mass (kg)	
% Variance To Target Mass	

Figure 51. Summary of the costs information of the cable holder.

Variable Costs	**Current (USD)**
Material Cost	<0.01
Labor	0.05
Direct Overhead	0.02
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.07
Period Costs	
Indirect Overhead	0.04
SG&A	0.01
Margin	0.00
Piece Part Cost	0.12
Fixed Costs	
▼ Hard Tooling (amortized)	0.01
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.01
Fully Burdened Cost	0.12
Capital Costs	
▼ Hard Tooling	7,915.17
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	7,915.17

Figure 52. Disglosed costs of the cable holder.

For this part, the manufacturing cost would be $0.12 and the initial investment would be $7,915.17.

There is also a need to calculate the cost of the screws, as some of them will be eliminated if these parts are modified. On that purpose, it was precise to search in a catalog system the ones that were the most similar. It was found that a pack of 100 4-40 threaded screws, half an inch long and made of zinc-plated steel had a cost of $7.16. Assuming that Proctor Silex would buy them in large quantities, it has been considered an approximation that they pay for each screw the fourth part of their original price. So, each hundred would cost them roughly $1.79, or what is the same, each screw would cost around 1.79 cents.

Lastly, it is going to be calculated the cost of the spring, as it can also be removed if the switch mechanism is modified. In the same catalog, it was found that a pack of 6 torsion springs similar to the one in our product, that has an outside diameter of 0.373”, a 120 degrees angle and a length at maximum torque of 1”, would cost $4.63 so, taking the same approximation that previously, each of the springs would cost to the company around 19.29 cents. (McMaster-Carr Suply Company 2019)

All this information is summarized in the following table:

Part	Qty.	Material cost	Piece part cost	Total amortized investments	Fully burdened cost	Total capital investments
Main cover	1	$0,17	$0,52	$0,02	$0,54	$23.491,72
Top cover	1	$0,07	$0,41	$0,02	$0,43	$24.675,72
Bottom cover	1	$0,18	$0,42	$0,01	$0,43	$13.004,96
Internal plate	1	$0,03	$0,19	$0,01	$0,20	$11.424,53
Cable holder	1	$0,01	$0,12	$0,01	$0,12	$7.915,17
Screw	15	$0,00	$0,00	$0,00	$0,27	$0,00
Spring	1	$0,00	$0,00	$0,00	$0,19	$0,00
	Total	$0,46	$1,66	$0,07	$2,18	$80.512,10

Table 7. Summary of the manufacturing costs of the parts under study.

12. Ideas for the new product

The objective of this re-designing process is to improve the manufacturability, assemblability and costs of the product under study, in this case by the removal of several parts that can be considered unnecessary and by the simplification of the assembly up to the limits marked by the mechanism itself. Those constraints are the following:

- Diameter of the bowl: The bowl needs to be assembled to the base of the appliance, so the cylindrical structure under it has to be necessarily kept. So, this is the minimum size that the base of this product can have.

- Height and diameter of the motor: There has to be an empty space in the case for the motor. It has cylindrical shape and has to be connected to the gears of the mechanism. Hence, there needs to be a cylindrical structure that does not only have to keep the motor inside but also leave some room for its cables. This structure may be the tallest part of the case, so the height of the motor will probably be determinant for the product's height.

- Assemblability of the motor: There is a not negligible difficulty on this facet, as the motor is going to be screwed to the base, so the fact of introducing it into the housing may get complicated. This has to be taken into consideration when developing the new designs.

- Fit of the gears: The final structure must guarantee a perfect fit of the gears. A new placement for their shafts must be found in the new parts, making sure that there is the right distance among them, but also taking into account the objective of minimizing space as much as possible. Also, the minimum height of the base will be determined by this mechanism.

Taking all those constraints into consideration, it is time to explore the possible solutions for the design. The first possibility that is going to be studied is a base with a hollow extrusion in form of a rounded prism, where the motor is going to be kept. Inside it, there must be a round plate in order to screw the motor, and enough space to introduce it from the bottom.

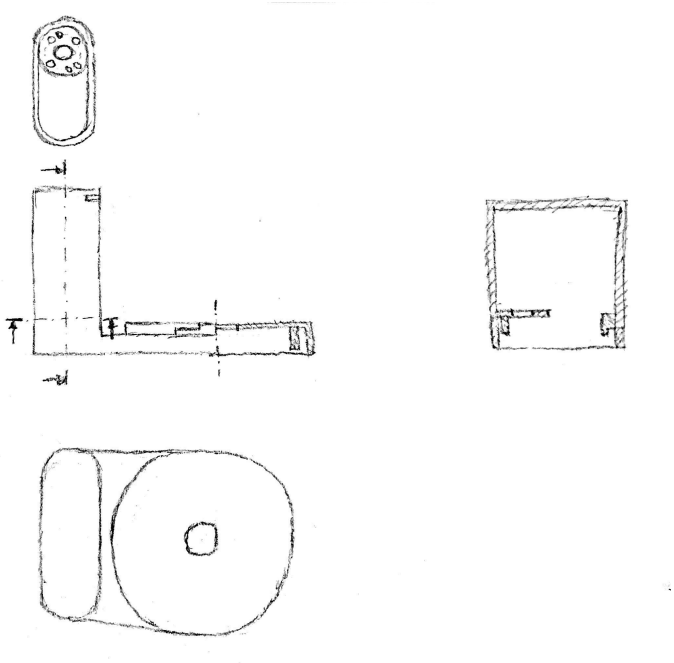


Figure 53. Hand sketch of the proposed case (1st design).

The bottom cover for this design will be quite similar to the original, but adapted to the shape of the new base. However, it would be necessary to create a shaft on it for one of the gears, which was assembled to the internal plate that has been removed. The other two gears will be attached to the shaft of the blades and to the motor. The main inconvenient of this is the necessity of too much empty space next to the motor to make possible its assembly.

The second option is a quite similar, but the motor is screwed to the cover instead of the case. This would solve the problem of the first one, since it would not be necessary to leave so much empty space, and it would be much easier to introduce the motor in the structure.

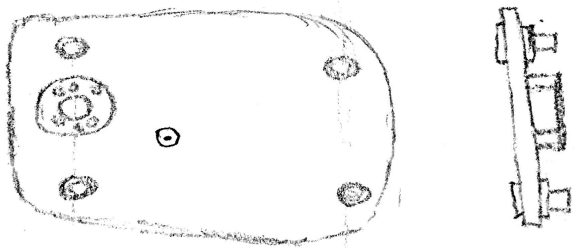


Figure 54. Hand sketch of the proposed cover (2nd design).

There is a platform a few centimeters over the lid where the motor will be located. It must be well separated because there must be enough space for the little gear on the shaft of the motor. Also, the support of this platform must be respectful with the gear mechanism. The problem that this design has is that it would be very difficult to screw the motor to the platform because there would not be much space for that.

The third option also includes the motor in the case, but it solves the problem of the space as well. It is quite similar to the first one, but one of the side surfaces of the cylinder is removed, so the motor can be easily introduced. Instead, the lid has L shape, so the uncovered section can be covered when assembled. In order to avoid the addition of more screws, on the top joint it will be studied the possibility of having a snap fit instead. This could even avoid some of the screws on the bottom part.

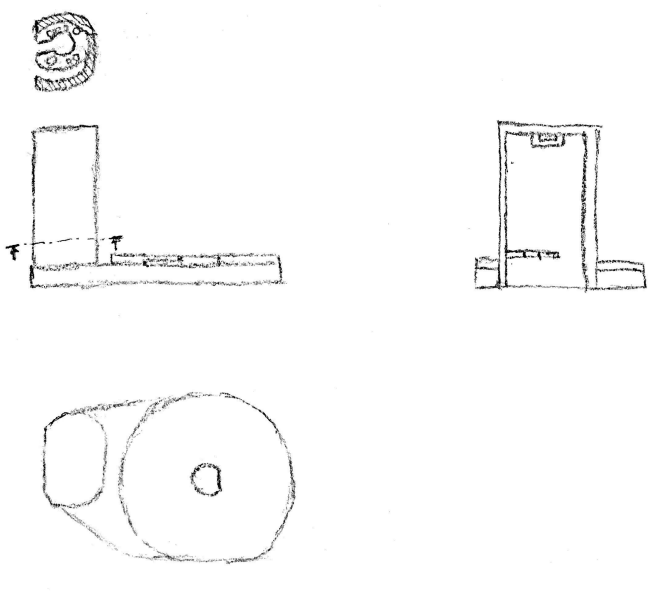


Figure 55. Hand sketch of the proposed base (3rd design).

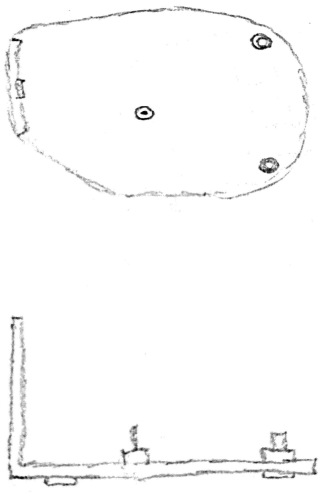


Figure 56. Hand sketch of the proposed cover (3rd design).

Although this option seems quite more advantageous, its design and mounting may be more difficult than the previous ones. Also, there are some possibilities that this can worsen the aesthetics of the product, so it is important to be careful with this aspect as well.

Apart from this, there are also several possibilities to locate the switch. The first one, and the easiest, is to leave the mechanism as it was in the original product. However, this could entail more height, as the switch was actuated by the lid when it was turned, so the cavity where the motor is held should be enlarged in order to reach that elevation.

Another possibility is to change that mechanism so the lid would not be necessary to activate the switch. For this, it would be requisite to create a button able to operate it. This is a more complicated option, but it could help reducing the height of the device. The first possibility is to put it in the same place, which is above the motor. This would only be beneficial if there was a clear saving of space with respect to the original mechanism, as it would also imply more height.

A problem shared by these two alternatives is that they would probably make impossible to eliminate the cavity over the motor that the original assembly had, so the top cover and its screws would not be removed. Only the L-shaped lid design would let do both things.

The third possibility is to create a button in a new location, probably in one of the sides. This may be quite more complicated, as it needs to adapt to the geometry of the part, but it is irrefutably the option that permits reducing the height the most, as the highest part of

the device will be the top of the motor. So, this alternative must be studied, although it is not clear if it would be too complicated to pay off.

Although it seems quite obvious that the best option for the motor may be the third design, for the switch it is not clear, but it can probably be either the first or the third one. However, in order to check all these suppositions it is convenient to do a deeper analysis for both parts. On that purpose, it will be helpful to elaborate a Pugh matrix with all the alternatives. The first column will be a list of the requirements that are being pursued and will help in the task of deciding which option is the best. Then, they are going to be given a value of weight, to measure their importance for the objective. The rest of the columns will be the different options that are being studied, which are going to be punctuated in a scale from -2 to 2. The alternatives for the motor and for the switch are going to be evaluated separately so that it is going to be possible to decide which will be the best option for both aspects.

Requirements	Wt.	Motor 1	Motor 2	Motor 3	Switch 1	Switch 2	Switch 3
Ease of assembly	10	1	0,5	2	0	0	0
Ease of design	8	-0,5	-0,5	-1	2	0	-1
Volume reduction	9	1	2	2	0	1	2
Part reduction	18	1	1	2	-0,5	-2	-1
Use of existing parts	12	1	1	2	2	1	1
Shape simplicity	7	0	0	-0,5	1	1	-1
Scores		45	49	86,5	38	-8	-3

Table 8. Pugh matrix of the 6 new designs.

Consequently, the assumption that the best option would be the one with the L-shaped lid was absolutely right, as it is the only one that will simultaneously ensure the highest ease of assembly and part reduction while using only existing parts. With the other two options, it is not clear if it would be possible to avoid the use of another top cover, and it would also be more difficult to introduce the motor into the case. Moreover, between the first and the third options for the switch mechanism and location, the chosen option will be the first one, which takes advantage of the previous system, as the other one involves a high difficulty on the design, since the space on a side is minimum and all the structure should be modified in order to situate the switch there. Also, that option would imply to create an additional plastic part for the button.

After having chosen the final option, it has been developed with more level of detail. In the following figures, the final projected design has been represented.

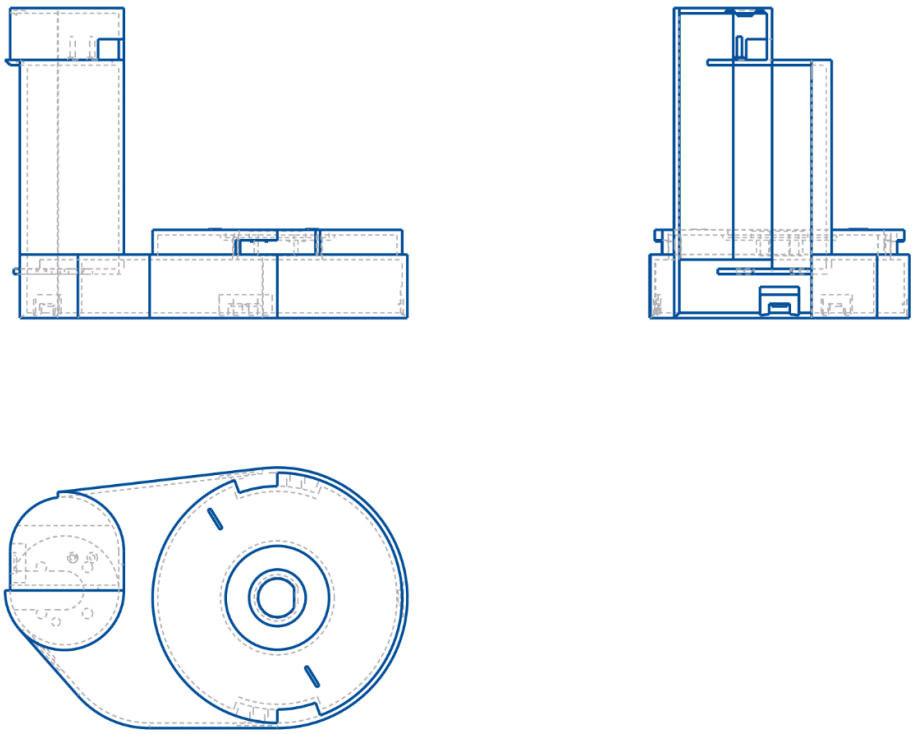


Figure 57. Detailed views of the new case.

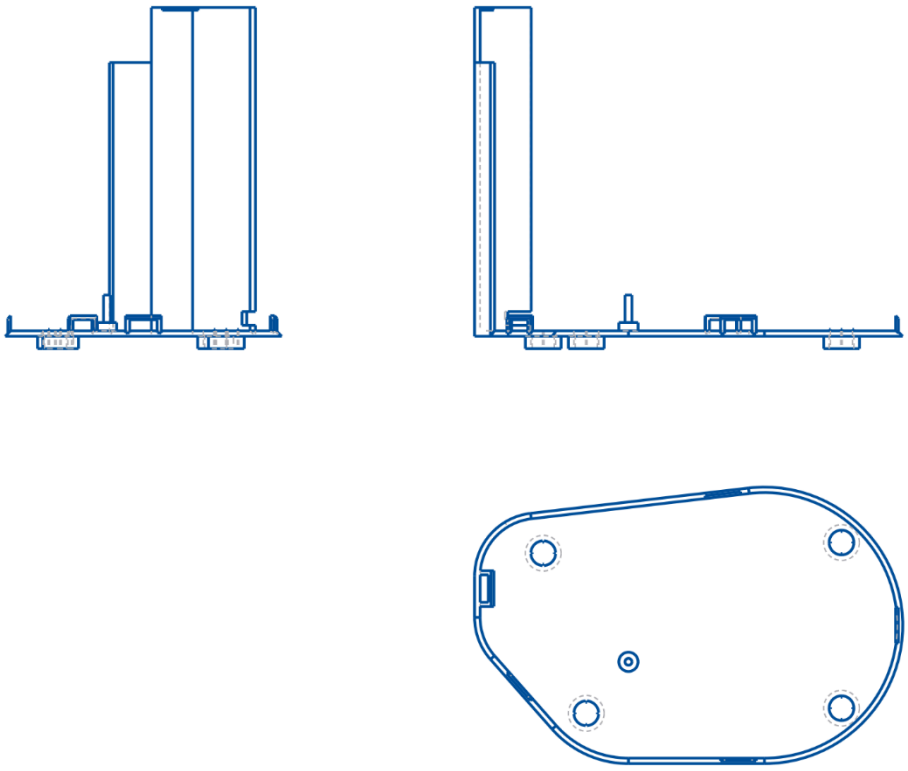


Figure 58. Detailed views of the new cover.

As it can be seen, the design is very similar to what it was previously sketched. However, there are a few new features that have been added. First, all the screws that used to join both plastic parts have been removed and substituted by snap fits, so that the final prototype will only need the pair of screws that fixed the motor to the base. This will represent an important saving if we take into account the massive quantities in which the product will be produced. Also, there will be a little cavity over the motor where the switch will be located, respecting the original mechanism, which will not be completely closed so as to avoid the need of an additional part to serve as a cover, as we previously had, and also to let the cables that connect it with the motor pass through. Finally, although there is no need to screw the cover to the case, four holes are going to be kept in the cover surface in order to introduce the little rubber stoppers that served as a support for the original product. This will help to avoid the wear of that part and also to increase the friction with the support surface, providing stability.

It is also precise to mention that the base has been optimized so that there is only the necessary space for the three gears, ensuring that their axis fit perfectly and there is enough room for the three of them, but trying to minimize the unnecessary gaps that there were on the original device. Also, it has been taken into account that the position of the third gear and, hence, the motor, did not interfere with the widening of the bowl.

13. CAD modeling of the new parts

In order to 3D model the new parts, the program that has been used was again Creo Parametric. This stage is necessary in order to then produce the first physical prototype. In the following figures, the result of this process can be seen.

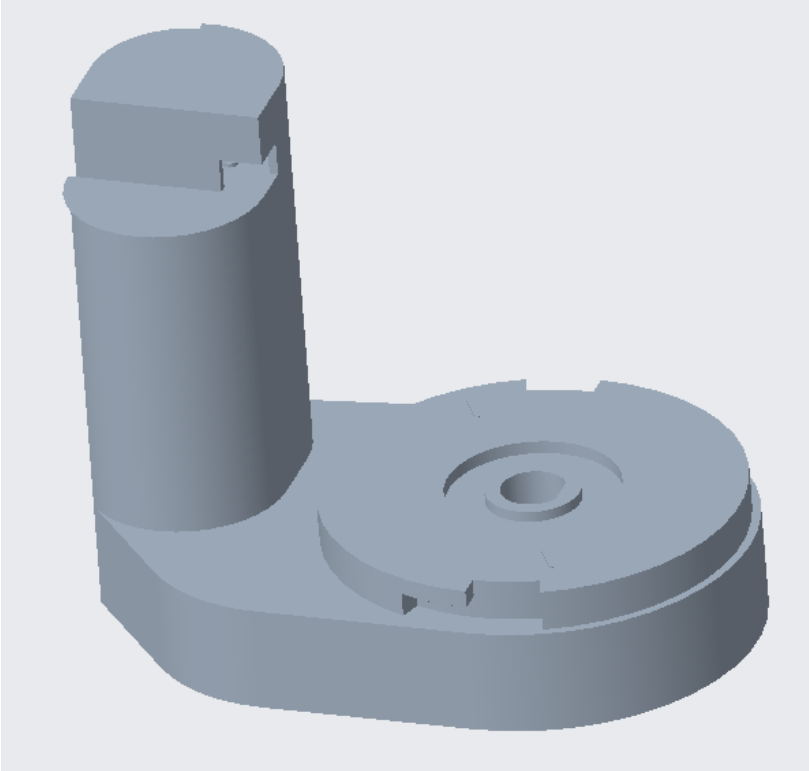


Figure 59. 3D model of the new main case

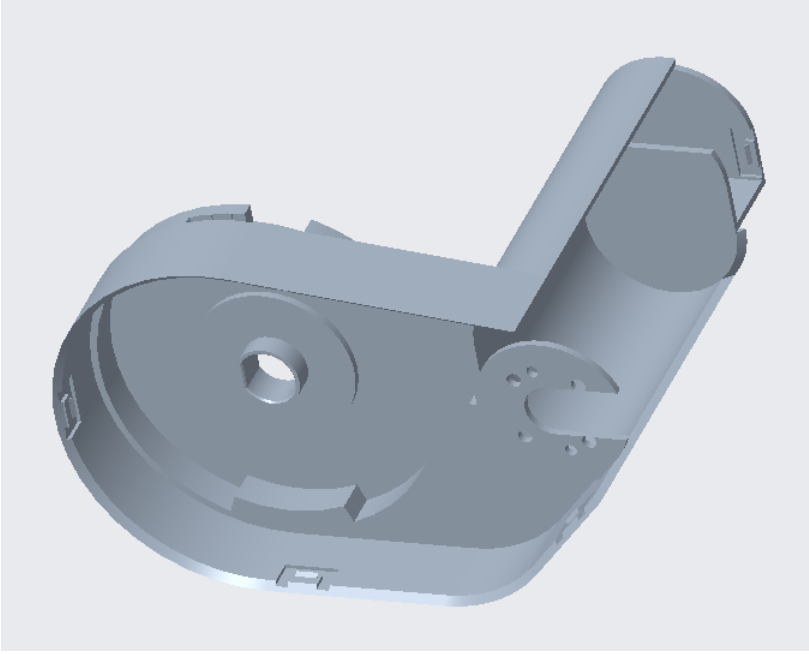


Figure 60. Another view of the new case.

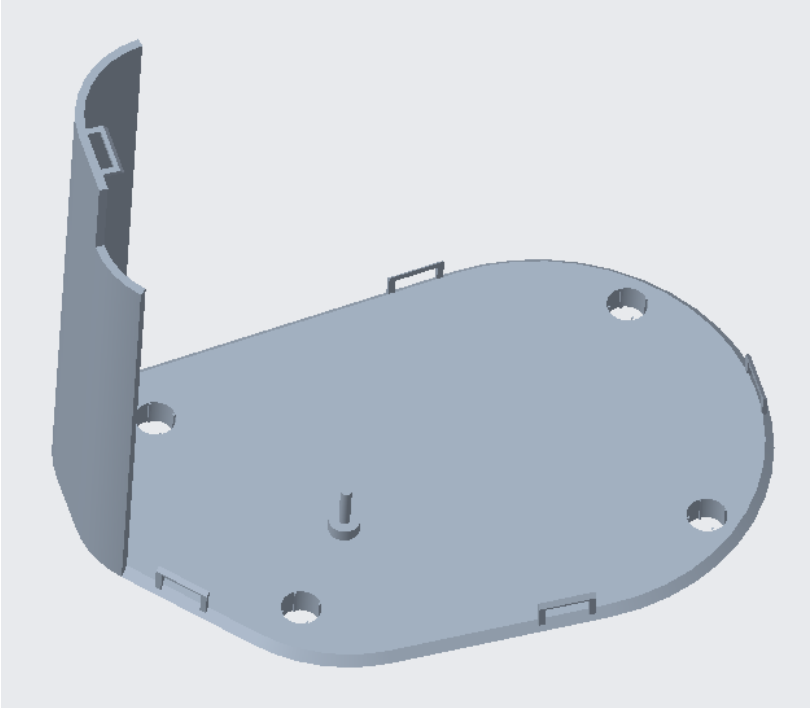


Figure 61. 3D model of the new cover.

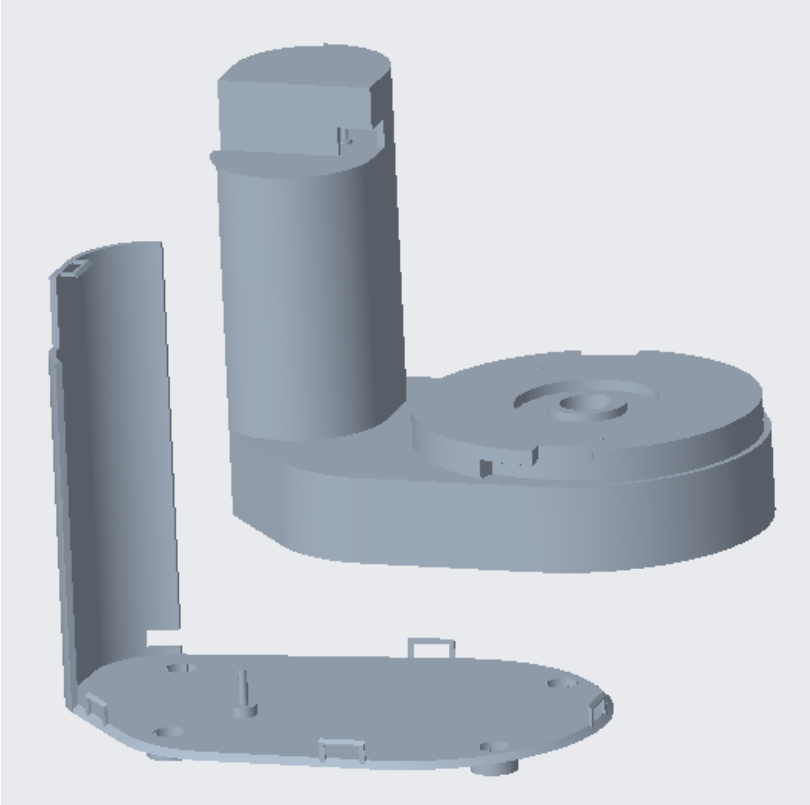


Figure 62. Simulation of the assembly of both parts.

14. 1st physical prototype

After being 3D modeled in Creo Parametric, the prototype of the new parts had to be manufactured. The technique used was 3D printing, which was carried out in the Innovation Studio of the Mechanical Engineering Lab, which belongs to the Grainger College of Engineering from the University of Illinois at Urbana-Champaign.

First, the .prt CAD files were exported to .stl, with and then introduced in Cura software, which is used to prepare .stl files for 3D printing. The obtained results are the following:

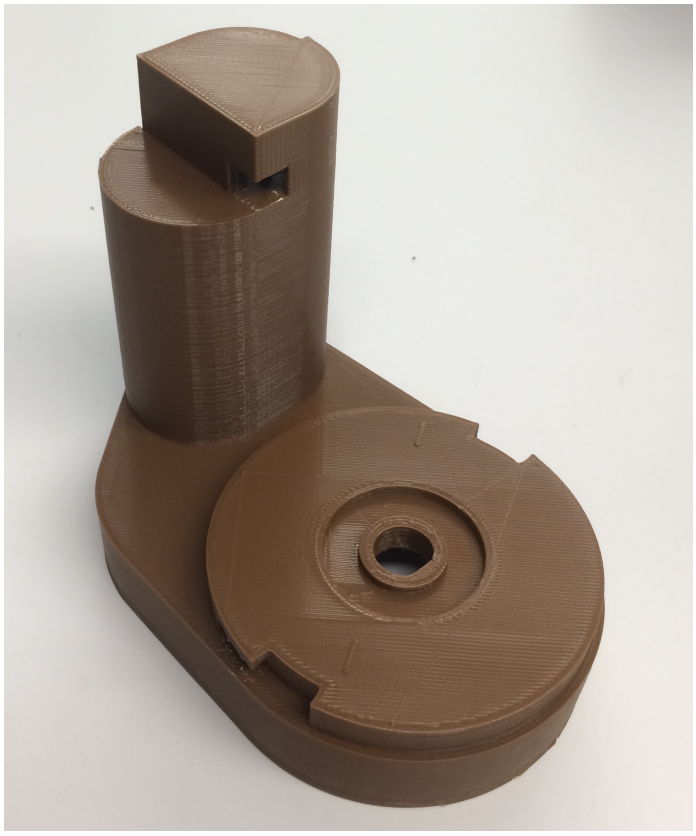


Figure 63. Prototype of the new main case.

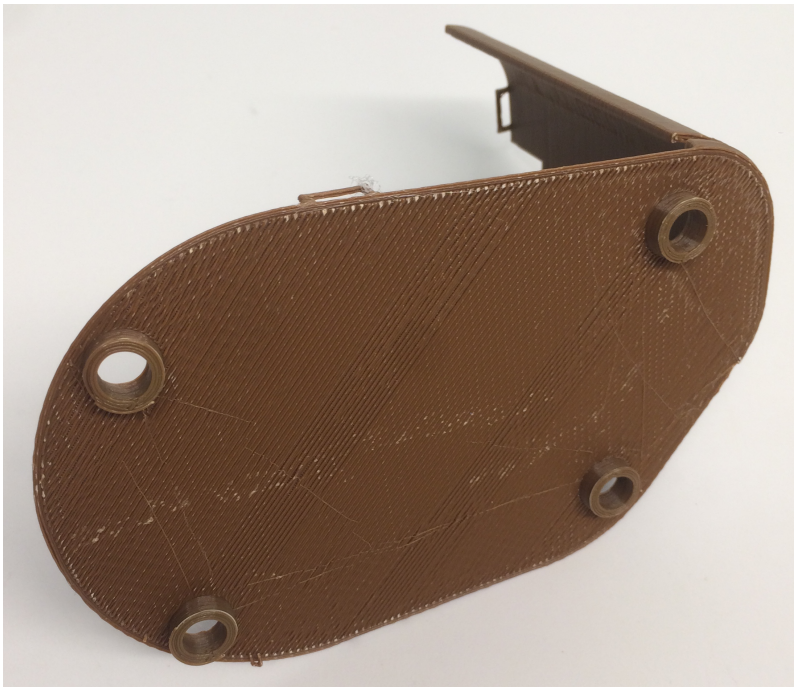


Figure 64. Prototype of the new bottom lid.

Once the new parts are manufactured, it is possible to assemble them and try out the operation of the re-designed device. First, the motor has to be screwed to its platform, and the gears must be collocated in their corresponding shafts.

Figure 65. Assembly of the motor.

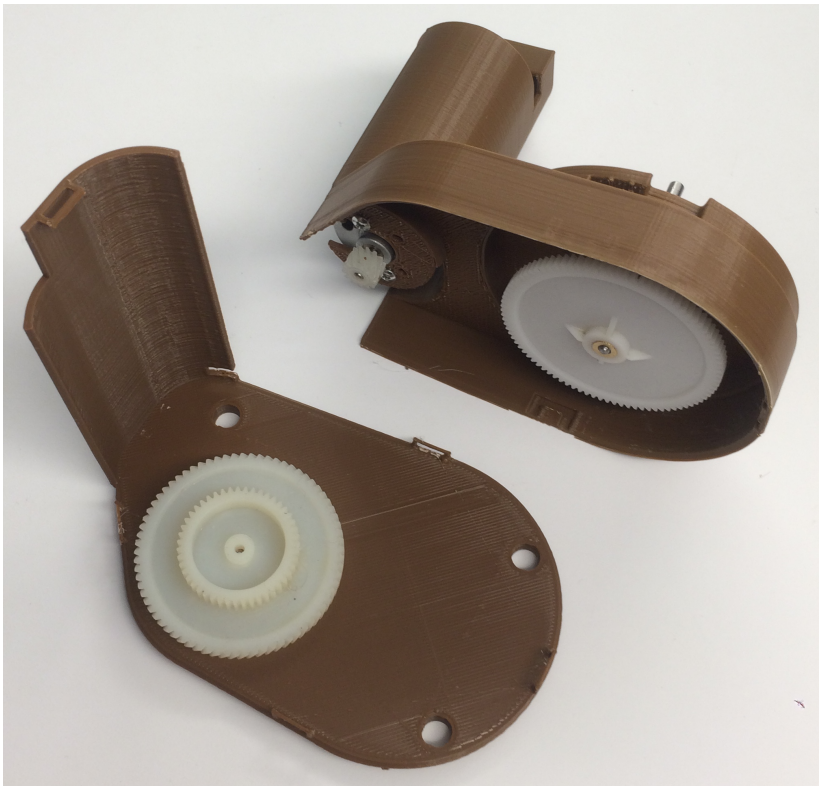


Figure 66. New location of the gears.

Then, the whole product can be assembled, with the help of the snap fits that have been added in the re-design and by placing the bowl and the blades in their usual location.

Figure 67. Final view of the new product.

15. Design of experiment method

Once the product is developed, it is time to make a rudimentary design of experiment method in order to test it with the redesigned parts. The objective of this process is to determine which variables are most influential on the studied response, and to set them on the values in which it is as near as possible to the target value, ensuring that it will present a small variability. The studied feature in this case will be the time that it takes to assembly the base of the appliance, which is the part that has been modified in this re-designing process so as to reduce this value. The input variables will be:

- Number of screws (x_1). The original device has 15, while the new one has just 2. Reducing the number of screws will also reduce the time of assembly.
- Number of plastic parts (x_2). The parts that are going to be considered are those that are injection-molded during the manufacturing process of the appliance, and not the ones that must be purchased to other companies. In the new base, the number of this kind of parts has been reduced to two, while in the original appliance there were five of them.

For this experiment, it has been chosen that a 2^2 factorial method is going to be used. This means that each of the factors, which are the input variables that have been previously detailed, will be given two levels: 'high', which in both cases is going to be the values present in the original device, and 'low', which will be the values with the new modified parts. The four possible combinations will be studied in order to find the most optimal.

FACTORS	LEVELS	
	Low (-)	High (+)
X_1: NUMBER OF SCREWS	2	15
X_2: NUMBER OF PLASTIC PARTS	2	5

Table 9. Values for the input variables.

After that, it is precise to make measurements of the values of the response for each treatment, which are the four possible combinations of factor values. Then, they can be represented in the following table:

Treatment combination	Factors			Response			Average response (s)
	x_1	x_2	Interaction x_1-x_2	Rep. 1	Rep.2	Rep. 3	
1	-	-	+	16,7	17,6	15,7	16,67
2	+	-	-	89,9	89,5	91,5	90,30
3	-	+	-	27,2	30,4	26,8	28,13
4	+	+	+	99	99,2	100,2	99,47
Contrast	144,97	20,63	-2,30				
Effect	72,48	10,32	-1,15				

Table 10. Design matrix.

In this table are collected the values of the estimated response in function of the different levels of the factors, as well as the levels of a hypothetical interaction between both. Then, it has been calculated the contrast of each of the parameters, which is the difference between the sum of the values of each factor at high level minus the sum of its values at low level, and the effect, which is the previous value divided by 2^{k-1}, in which k is the number of factors (in this case, k=2).

The next step is to do an analysis of the variance, or ANOVA, in order to verify which of the effects are significant. On that purpose, confidence intervals will be used. So, its needed to calculate the variance of the response. Once that value is known, it is possible to find the standard error, which is the square root of the variance.

$$S^2 = \frac{1}{4(n-1)} \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{n} \left(y_{ijk} - \bar{y}_{ij}\right)^2$$

$$= \frac{1}{4}[(16.7 - 16.67)^2 + (17.6 - 16.67)^2 + (15.7 - 16.67)^2$$
$$+ (89.9 - 90.3)^2 + (89.5 - 90.3)^2 + (91.5 - 90.3)^2$$
$$+ (27.2 - 28.13)^2 + (30.4 - 28.13)^2 + (26.8 - 28.13)^2$$
$$+ (99 - 99.47)^2 + (99.2 - 99.47)^2 + (100.2 - 99.47)^2] = 3.165$$

$$s.e. = \sqrt{\frac{3.165}{2}} = 1.258$$

Equation 1. Calculation of the variance and the standard error of the different replicates.

With this value, the confidence intervals of each for each effect can be calculated. This can be done, with a 95% of confidence, by adding and subtracting the standard deviation multiplied by two to the means of each of the effects. Once those intervals are obtained,

it can be inferred that those which do not contain 0 will belong to the effects that can be considered significant.

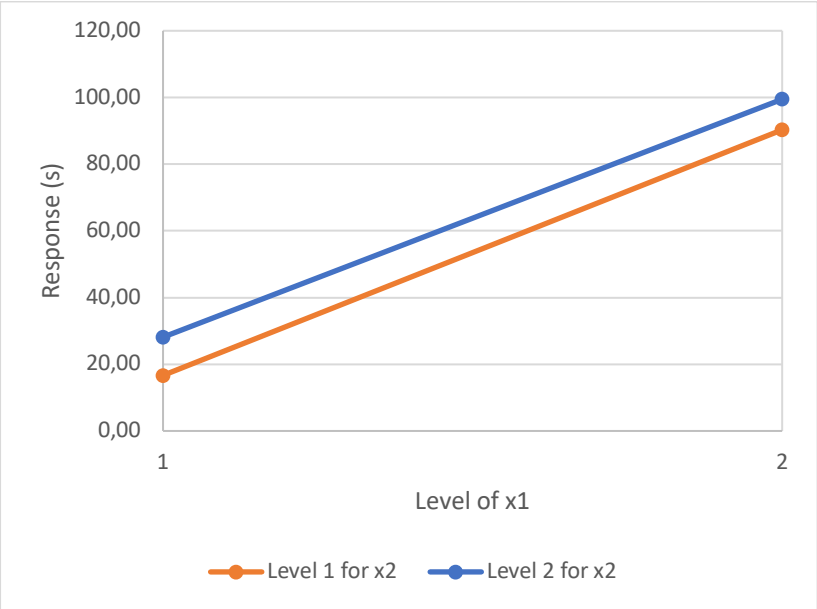
$$Factor\ x_1 = 72.48 \pm 2 \times 1.258 = [60.964, 74.996]$$

$$Factor\ x_2 = 10.32 \pm 2 \times 1.258 = [7.804, 12.836]$$

$$Interaction = -1.15 \pm 2 \times 1.258 = [-3.666, 1.366]$$

Equation 2. Confidence intervals of each factor and interaction.

Consequently, both of the factors that are being studied in this experiment are significant, but their interaction is not. This can be seen in the following graphic, which represents the different average responses depending on the factor levels. In that graphic, it can be appreciated that both lines are almost parallel, which means that there is not significant interaction between both factors.



Graphic 1. Responses for the different factor levels.

16. Comparison with the original product

16.1. Cost analysis

In order to compare the costs of both products, the 3D models of the new parts have been introduced in aPriori, which was previously used for the original components. In Figure 55 and 56, we can see the results of the cost calculation for the new case and cover.

Variable Costs	**Current (USD)**
Material Cost	0.14
Labor	0.11
Direct Overhead	0.15
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.41
Period Costs	
Indirect Overhead	0.11
SG&A	0.04
Margin	0.00
Piece Part Cost	0.55
Fixed Costs	
▼ Hard Tooling (amortized)	0.04
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.04
Fully Burdened Cost	0.59
Capital Costs	
▼ Hard Tooling	49,671.30
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	49,671.30

Figure 68. Detailed manufacturing costs of the new case.

Variable Costs	Current (USD)
Material Cost	0.08
Labor	0.14
Direct Overhead	0.19
Amortized Batch Setup	<0.01
Logistics	0.00
▼ Material Overhead	<0.01
Expendable Tooling	0.00
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.41
Period Costs	
Indirect Overhead	0.13
SG&A	0.04
Margin	0.00
Piece Part Cost	0.59
Fixed Costs	
▼ Hard Tooling (amortized)	0.02
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.02
Fully Burdened Cost	0.61
Capital Costs	
▼ Hard Tooling	23,561.09
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	23,561.09

Figure 69. Detailed manufacturing costs of the new cover.

	ORIGINAL PRODUCT		NEW PRODUCT	
	Capital investment	Part cost	Capital investment	Part cost
Case	23491.72	0.54	49671.30	0.59
Bottom cover	24675.72	0.43	23561.09	0.61
Internal plate	13004.96	0.43	-	-
Top cover	11424.53	0.20	-	-
Cable holder	7915.17	0.12	-	-
Screws	0	0.27	0	0.03
Spring	0	0.19	-	-
TOTAL	80512.10	2.18	73232.39	1.23
DIFFERENCE	7279.71	0.95		

Table 11. Comparison of the capital investment and the cost per part.

In this table, there is a comparison between the total capital investment and the fully burdened cost for each part, both in the original product and in the new one. Data of the original product have been extracted from the calculation done previously in chapter 11. As we can see, although the new case needs a bigger investment in machinery owing to the complexity of its shape, in total there is a saving of $7279.71 in instrumentation thanks to the reduction in the number of parts that has been carried out. Moreover, the new spent per product in these parts will be $1.23, which represents $0.95 less per appliance, that is to say, a reduction of the 43.58% of their initial cost. This means a saving of $241,300 per year in production.

16.2. Time of assembly

Now, we are going to make an estimation of the time that it would last to assemble the whole product, by using the tabulation tables. The approximated time of assembly will be calculated for both the original and the new product, but only considering the plastic parts and the screws. The other parts (motor, gears, …) are going to be neglected in order to simplify the calculations. Also, all of the screws are going to be considered to be less than 2 cm and not sharp, as most of them fulfill these characteristics.

First of all, we are going to calculate the time of assembly of the original product. In Table 11, all the parts that are going to be put together have been represented, with their angles of symmetry and some of their characteristics.

	α	β	Difficulties	Snap fits	Number
Screws	360	0	-	-	15
Cover	360	360	2 hands	0	1
Internal plate	360	360	2 hands	0	1
Top cover	360	360	2 hands	0	1
Cable holder	180	180	2 hands	0	1

Table 12. Parts in the original product.

a. Handling and alignment time:
   i. Screws: 0.5s + 1s (symmetry) + 0.5s (small) = 2s
   ii. Cover: 0.5s + 2s (symmetry) + 0.4 (difficulty) = 2.9s
   iii. Internal plate: 0.5s + 2s (symmetry) + 0.4 (difficulty) = 2.9s
   iv. Top cover: 0.5s + 2s (symmetry) + 0.4 (difficulty) = 2.9s
   v. Cable holder: 0.5s + 1s (symmetry) + 0.4 (difficulty) = 1.9s

b. Insertion and secure time:
    i. Screws: 0.5s + 0.3s (medium hole) + 1s (turning insertion) + 2s (one-sided tightening) = 3.8s
    ii. Cover: 0.5s
    iii. Internal plate: 0.5s
    iv. Top cover: 0.5s
    v. Internal plate: 0.5s
c. Total time: 15 · 2s + 3 · 2.9s + 1.9s + 15 · 3.8s + 4 · 0.5s = 99.6s

Secondly, we must now estimate the same value with the new parts.

Parts	α	β	Difficulties	Snap fits	Number
Screws	360	0	No	-	2
Cover	360	360	2 hands	5	1

Table 13. Parts in the new product..

a. Handling and alignment time:
    i. Screws: 0.5s + 1s (symmetry) + 0.5s (small) = 2s
    ii. Cover: 0.5s + 2s (symmetry) + 0.4 (difficulty) = 2.9s
b. Insertion and secure time:
    iii. Screws: 0.5s + 0.3s (medium hole) + 1s (turning insertion) + 2s (one-sided tightening) = 3.8s
    iv. Cover: 0.5s + 5 · 0.3s (snap fits) = 2s
c. Total time: 2 · 2s + 2.9s + 2·3.8s + 2s = 16.5s

From these calculations it can be inferred that there is a difference of 83.1 seconds between both. This means a reduction of more than a 600%, which is absolutely relevant because assembly costs represent from 10% to 50% of the total manufacturing costs.

Conclusion

The results of weeks of redesigning work have been evidenced in the previous chapters. Although they would require a capital investment of $73,232.39, this will be soon amortized, as the savings that it would involve are much more abundant. The expenditure of money in materials would be reduced by $241,300 annually, and the assembling process, which causes from 10 to 50% of the whole production costs, will be much simpler and more than 6 times faster. All this will give the company an opportunity to generate huge additional profit at a medium-long term.

Apart from reducing the number of parts, the functionality of the product was also improved. The volume was reduced to its minimum, so that it will occupy less space in a kitchen, and the weight was also reduced in order to be more manageable. Furthermore, its lower center of gravity makes it be even more stable than the original product was.

Moreover, all those changes have been made without affecting the aesthetics of the product. What is more, the simplification of the shapes makes this appliance seem more elegant. Also, the widening of the range of colors, which was previously limited to white and black, can make it even more attractive for the public.

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