



# GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

Analysis and redesign for manufacturability of head-mount  
magnifier from YOCTOSUN

Autor: José Ignacio Cabanelas Estévez

Director: Leon Liebenberg

Madrid

Julio de 2019



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**ANALYSIS AND RE-DESIGN FOR MANUFACTURABILITY OF HEAD-MOUNT  
MAGNIFIERS FROM YOCTOSUN**

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Fdo.: José Ignacio Cabanelas Estévez      Date: 14/07/2019



I authorize the submission of this project

**PROJECT SUPERVISOR**



L. Liebenberg

Fdo.: Leon Liebenberg

Date: 14/07/2019





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# Análisis y rediseño para la fabricación de las gafas de aumento ajustables para cabeza de YOCTOSUN

**Autor: José Ignacio Cabanelas Estévez**

Director: Leon Liebenberg

Entidad colaboradora: ICAI – Universidad Pontificia Comillas

## RESUMEN DEL PROYECTO

### 1. Introducción

Diseño de Fabricación y Diseño de Montaje son dos campos de estudio que analizan un objeto y las posibilidades de mejora que tiene su proceso de producción. La principal meta de estas herramientas es descubrir algunos aspectos en el producto (proceso de fabricación, tiempo de montaje, número de piezas...) que puedan ser revisados para obtener o bien una reducción de costes o bien una mejora en la funcionalidad del mismo.

Con este contexto en mente, el producto que ha sido elegido en este proyecto para ser estudiado son las gafas de aumento ajustable para cabeza de YOCTOSUN, una empresa china que solo comercializa sus productos en su país y en Estados Unidos. Este es el principal objeto que comercializan, y el único distribuidor con licencia para venderlo en el país americano es Amazon.

Además, es pertinente ver cuáles son las principales tendencias del mercado donde las gafas se encuentran (en este caso, el mercado óptico). En general, la vista de las personas se está viendo afectada por el uso de aparatos electrónicos, por lo que hay una tendencia ascendente de problemas de visión y también de gente ciega. Por otro lado, los mercados ópticos americanos y asiáticos representan más de un 50% del mercado óptico global. Asimismo, evaluando la posición de las gafas dentro del mercado, una buena relación calidad-precio es la principal atracción de sus compradores, un factor a tener en cuenta en el desarrollo del trabajo.

### 2. Metodología

El primer paso para comenzar correctamente el estudio es desmontar el objeto y familiarizarse con él. Una lista de todos los componentes junto con algunas características es necesaria para poder echarle un vistazo rápido en cualquier momento del proyecto.

Posteriormente, el estudio de mercado anteriormente mencionado permite ver cómo las gafas se han adaptado y se adaptan al mercado. Una vez que este está hecho, también es pertinente una estimación del coste de fabricación y de la identificación de técnicas de fabricación presentes en el objeto, ya que estos van a ser dos de los ejes principales del trabajo.

De igual forma, es crucial entender lo que los clientes esperan del producto cuando lo compran, por lo que se elaborará un Despliegue de la Función de Calidad (DFC). Este es una tabla donde se exponen todas las necesidades del cliente y las características del objeto, de tal manera que se pueden extraer conclusiones para descubrir los principales aspectos que deben de ser mejorados. Consecuentemente, este despliegue servirá para identificar las áreas donde concentrar el foco del estudio.

Con este análisis en mente, son igualmente importantes un modelo en 3D de la parte del objeto que se decida estudiar, así como una lluvia de ideas usando técnicas de diseño de fabricación y de montaje. Después de esto, se empleará la Matriz de Pugh (una herramienta para comparar distintos conceptos e innovaciones) para seleccionar la idea más prometedora.

En este sentido, es crítico hacer un análisis lo suficientemente aproximado de las distintas proposiciones, dado que una vez que se seleccione una, es complicado volver atrás. La nueva idea será también diseñada e impresa en 3D para poder probar su funcionalidad cuando se monte junto con el producto entero.

Finalmente, se llevará a cabo una comparación entre la versión original y la nueva versión de las gafas. Esta estará basada en la diferencia de tiempo de montaje y en los costes de fabricación, por tanto, en los beneficios que los cambios en estas variables pueden aportar a la compañía.

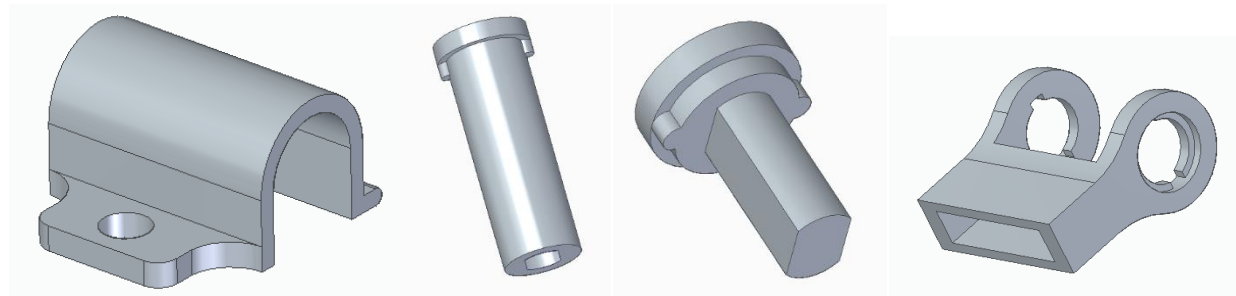
### 3. Resultados

Después de elaborar el estudio de mercado y las implicaciones que este tendrá en el trabajo, se realizó una estimación de los costes de fabricación del producto. Teniendo en cuenta que el producto es vendido a \$16,79, añadido al hecho de que los costes de fabricación de productos de plástico hechos con moldeo por inyección suelen suponer un tercio del precio final total, se estimó que el precio de producir unas únicas gafas es de \$5,5.

Seguidamente, el primer Despliegue de la Función de Calidad (DFC) expuso ciertos factores que ayudan a encarar los próximos pasos a ejecutar en el proyecto. Después de rellenar la tabla con la importancia de cada necesidad y de cada característica y de hacer los cruces entre todos estos para ver cuáles tenían relación con

otros, se puso de manifiesto que los clientes valoran aspectos como el bajo coste, la facilidad de ponerse las gafas y el buen aumento de las lentes. Por otro lado, las características que más destacaron fueron la distancia focal (la cual está claramente relacionada con el buen aumento de las lentes), y el coste del producto. Después de reconsiderar otra vez lo que un cliente espera de unas gafas de aumento como estas y observando con más detalle las características del producto, se añadieron nuevas como la probabilidad de rotura o la esperanza de vida; así como nuevas necesidades como la estabilidad de las pilas y la movilidad y limpieza de las lentes.

El análisis elaborado en el DFC, con la ayuda del análisis de diseño de fabricación, llevaron a la decisión de concentrar el esfuerzo de rediseño en el ajustador de lentes de las gafas (la parte que une la carcasa principal con las lentes). Esto fue así porque se consideró que era la parte que más posibilidades de mejora ofrecía. Este componente está hecho a su vez de cuatro piezas: la carcasa grande, la carcasa del medio, un cilindro grande y otro cilindro pequeño. Una vez se eligió el ajustador de lentes, se diseñó esta parte en 3D con Solid Edge, y el resultado de este diseño fue el siguiente:



El siguiente paso después de tener el modelo en 3D fue estimar los costes de fabricación de cada uno de los componentes del ajustador (de tal manera que sea posible compararlos con la pieza rediseñada en un futuro). Esto se realizó con la ayuda del programa *A priori*, proporcionado por la University of Illinois at Urbana-Champaign. Introduciendo la estimación de que se producen 25.000 unidades de estas gafas de aumento al año, los costes serían los siguientes:

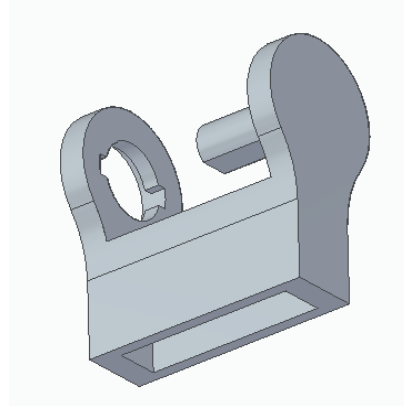
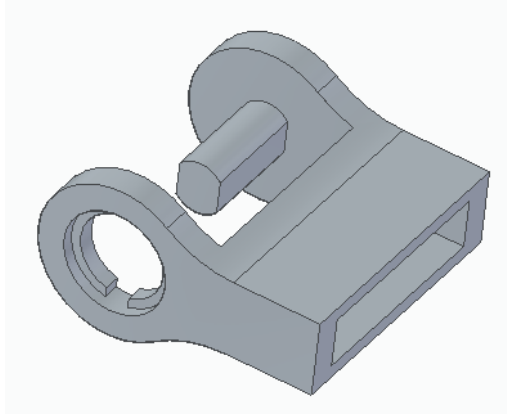
<b>Componente</b>	<b>Costes Variables Totales (\$)</b>	<b>Coste Fijo de Pieza(\$)</b>	<b>Coste Total Amortizado (\$)</b>
<b>Carcasa Principal</b>	0.07	0.14	0.16
<b>Carcasa del Medio</b>	0.05	0.08	0.10
<b>Cilindro Grande</b>	0.17	0.28	0.30
<b>Cilindro Pequeño</b>	0.13	0.22	0.24

Una vez se sabe que el precio de fabricar unas únicas gafas de aumento es de alrededor \$0,80, se puede tratar de reducir este precio. Debido a esto, se llevó a cabo una lluvia de ideas donde las principales propuestas fueron divididas entre aquellas que estaban destinadas a mejorar la funcionalidad y aquellas que estaban destinadas a reducir costes de producción. Por un lado, se propuso añadir un visor al ajustador (y así poder levantar las lentes sin ensuciarlas, saciando el deseo de los clientes de no tener que tocarlas cada vez que son levantadas o bajadas), y también un cambio de forma del mismo (con el mismo objetivo, al ser más grueso el sitio por donde se coge). Por el otro lado, la principal idea para conseguir reducir costes fue combinar varios elementos del objeto de estudio, de tal manera que el precio de fabricarlo sea más pequeño. Más tarde, este planteamiento fue dividido en dos subideas: juntar la carcasa principal con el cilindro grande o combinarla con el cilindro pequeño.

Después de hacer esta lluvia de ideas, se necesita una herramienta para poder compararlas y seleccionar la más prometedora. Para desempeñar esa función, se utilizó la Matriz de Pugh, la cual es muy útil para contrastar las propuestas en relación con lo que los clientes esperan del producto:

Necesidad del cliente	Importancia	Visor	Cambio de forma	Montaje 1	Montaje 2
Fácil de usar	6	1	0	0	0
Coste Bajo	7	-1,5	-1	1,5	2
Durabilidad	5	0	0,5	0	0
Movilidad y limpieza de las lentes	6	2	0,5	0	0
Fragilidad	5	-1	1	0	0
<b>Score</b>		<b>2,5</b>	<b>3,5</b>	<b>10,5</b>	<b>14</b>

Así pues, la idea que se eligió para continuar con el proyecto fue unir la carcasa principal con el cilindro pequeño en una sola pieza. Esta combinación permitiría presumiblemente una reducción mayor en los costes de fabricación que la idea del otro montaje, pues introducir el pequeño en el montaje entero sería más costoso que introducir el grande. El primer modelo en 3D de la pieza rediseñada fue el siguiente



El siguiente paso natural fue comprobar la funcionalidad de este diseño a la hora de implementar el cambio en el objeto entero. Para ello, se imprimió en 3D en el Innovation Studio del Mechanical Engineering Building en la University of Illinois at Urbana-Champaign. Las dimensiones en este primer intento resultaron no ser apropiadas dado que el cilindro pequeño no encajaba en el hueco reservado para él en el cilindro grande, por lo que hubo que rediseñarlo de nuevo. Así, después de aumentar las tolerancias, la nueva versión fue impresa al 100% de sus dimensiones, al 102% y al 104%. Finalmente, fue la primera de estas la que encajó bien con toda la pieza:



#### 4. Conclusiones

Todo este proceso no tendría sentido si no se hiciese una comparación final entre el ajustador original y el modificado. Debido a esto, se llevó a cabo un contraste final con las características de ambas versiones.

Para empezar, se calcularon los tiempos de montaje de las gafas enteras para el diseño antiguo y para el nuevo. Mientras antes llevaba 94 segundos unir todas las piezas de las gafas, con el diseño nuevo resultó ser 90,2 segundos. Esta diferencia podría permitir obtener un aumento considerable en los beneficios de YOCTOSUN. Recordando la estimación de que se fabrican 25.000 unidades de estas gafas al año, en este intervalo de tiempo la empresa se puede ahorrar  $25.000 \times 94 = 2.350.000$  segundos, es decir, alrededor de 650 horas de trabajo. Con este dato, se pueden calcular el total de unidades “extra” que se podrían producir por año:

$$\frac{\text{Tiempo de montaje total en un año}}{\text{Tiempo de montaje para unas únicas gafas}} = \frac{2,350,000 \text{ segundos}}{90,8 \text{ segundos}} = 25.881 \text{ unidades}$$

Por tanto, dado que se podrían producir alrededor de 900 unidades más de este producto, YOCTOSUN tiene diferentes opciones para aprovechar este aumento y ganar ventaja competitiva sobre sus competidores.

Además, analizando los costes de producción, de nuevo, con la ayuda de *APriori*, obtenemos las siguientes estimaciones sobre los costes de fabricación en el nuevo ajustador:

Component	Total Variable Costs	Piece Part Cost	Fully Burdened Cost
Main Shell	0.07	0.14	0.16
Small Cylinder	0.13	0.22	0.24
Sum of the two parts	0.20	0.36	<b>0.40</b>
Redesigned part	0.08	0.14	<b>0.17</b>

Por tanto, ha tenido lugar una considerable reducción en el coste de producción: producir la carcasa principal y el cilindro pequeño por separado suponía un coste de \$0,40, mientras producir este nuevo modelo cuesta \$0,17, por lo que se ahorran \$0,23 por cada una de las gafas que se producen. Así pues, si se fabrican 25.000 unidades al año, la cantidad que se ahorraría YOCTOSUN solo en costes de fabricación sería:

$$\text{Cantidad ahorrada} = 25.000 \text{ unidades} \times \$0,23 = \$5.570$$

# Analysis and redesign for manufacturability of head-mount magnifier from YOCTOSUN

**Author: José Ignacio Cabanelas Estévez**

Director: Leon Liebenberg

Collaborating entity: ICAI – Universidad Pontificia Comillas

## PROJECT SUMMARY

### 1. Introduction

Design for Manufacturability (DfM) and Design for Assembly (DfA) are two fields of study that analyze an object and study the possibilities to improve its production process. The main goal of this tools is discovering some aspects in the item (manufacturing process, assembly time, number of pieces) that can be revised in order to achieve a reduction in production costs or an improvement in the functionality of it.

With this context in mind, the product that has been chosen in this project to be studied is the head-mount magnifier glasses from YOCSTOUN, a Chinese company that only commercialize its items in the United States and in China. This is the main product that they commercialize (apart from other technological items), and the unique distributor allowed to sell this magnifier is Amazon.

Furthermore, it is pertinent to see which the main growth trends are in the market where the YOCTOSUN product is involved (in this case, the eye-wear market). In general, people's sight is being affected by the use of electronical devices, so there is an increasing trend of vision loss problems and blind people. Also, North America and Asia Pacific eye-wear market stand for more than 50% of worldwide eye-wear market. Moreover, evaluating the position that the magnifier is located in the market, a good value for money is what mainly attract to its buyers.

### 2. Methodology

The first step to precisely begin this process is disassembling the product of study and become familiar with it. A list of all the components is necessary so it is possible to take a quick look on the parts at any time of the analysis.

Next, a market study is required to see the main trends of it and how the magnifier can adapt to them. Once this is done, it is also pertinent an estimation of the manufacturing cost and an identification of the manufacturing techniques present in the magnifier, as it is going to be the focus of the project.

Besides, it is necessary to understand what the customers expect when they buy this product, so a Quality Function Deployment (QFD) will be performed. This is a table where all the customer requirements meet the product specifications so conclusions can be drawn in order to discover the main aspects of the product to be improved. Consequently, this study will serve to discover the areas to concentrate the design efforts.

With all this analysis in mind, a CAD modeling and a manufacturing cost of the existing product are needed, as well as a brainstorm of ideas using design for manufacturability and assembly techniques. After this, the best idea will be selected using a Pugh Matrix (a tool to compare those new concepts).

In this way, it is very critical to do an accurate analysis of the existing ideas, because once that the most promising concept is chosen, it is not easy to come back. This idea will be CAD modeled and 3D printed, and an experiment will be designed to prove the functionality of the new piece when it is assembled with the whole product.

Finally, a comparison between the original magnifier and the new version will be performed. This analysis will be focused on the difference in the manufacturing and the assembly time and, therefore, in the profits that this change can mean to the production costs and the profits to the company.

### 3. Results

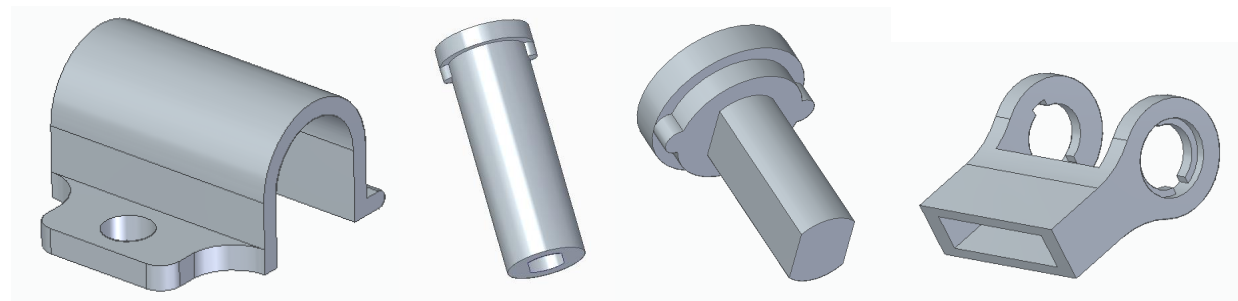
After performing the market study and the implications that it will have on the project, an estimation of the manufacturing costs of the item must be made, as this was one of the focus of improvement. Taking into account that the product is sold at \$16.79, added to the fact that the manufacturing costs of most plastic objects made with injection molding techniques account for



one third of the final total sales product, the estimation was that the manufacturing cost of one magnifier is \$5.5.

Next, the first QFD showed several factors that helped to face the following steps of the project. After filling the table with the importance of each characteristic of the product and each customer requirement, and doing the pertinent crosses of all of them, it was showed that customers valued more the low cost, the ease to wear and use them or the good magnification more than its durability (life expectancy). In the same way, the most important functional requirements turned out to be the focal length (which is clearly related to a good magnification), and the cost. After rethinking about what a buyer of the magnifier expects and observing with more detail the object and the customer reviews, new features as the breakage probability or the life span, as well as new customer requirements as the stability of the batteries or the mobility and cleaning of the lenses, were considered.

The analysis performed in the updated QFD, with the help of the Design for Manufacturability analysis, led to the decision to concentrate the design effort on the lenses adjuster of the magnifier, as it was the part with more opportunities to improve whether these most important customer requirements or the most relevant features of the product. This component of the magnifier is made up of four parts: the main shell, the medium shell, the big cylinder and the small cylinder. Once this choice was made, this part had to be CAD modeled. The program used to do this sketch was Solid Edge, and the first prototype of the lenses adjuster was the following:



The next step after having these 3D models of the studied part is to perform an estimation of the manufacturing costs of each one of these components (so it will be possible to compare, in the future, the re-designed product with the previous one). With the help of the program *APriori*, it

was estimated that, if about 25,000 magnifiers are produced per year, the costs of producing each part of the lenses adjuster are showed in the next table:

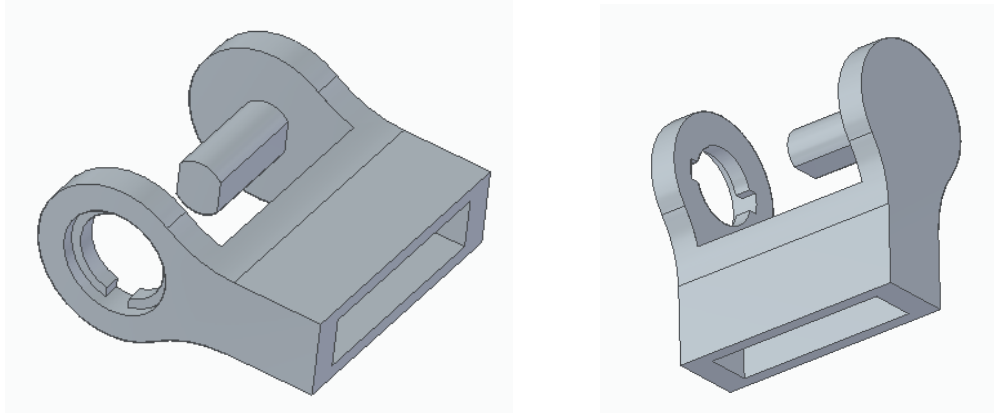
<b>Component</b>	<b>Total Variable Costs (\$)</b>	<b>Piece Part Cost (\$)</b>	<b>Fully Burdened Cost (\$)</b>
<b>Main Shell</b>	0.07	0.14	0.16
<b>Medium Shell</b>	0.05	0.08	0.10
<b>Big Cylinder</b>	0.17	0.28	0.30
<b>Small Cylinder</b>	0.13	0.22	0.24

Once that it is known that the price of manufacturing one single lenses adjuster will be around \$0.80, it is time to try to reduce this cost. Because of this, a brainstorm of ideas was carried out. The main purposes were divided into improving the functionality and reducing the manufacturing costs. On the one hand, the ideas that came up in the first group were adding a visor to the adjuster (so the customer requirement of “mobility and cleaning of the lenses was completely fulfilled as the lenses would not need to be touched) and changing the form, with the same purpose of the previous idea. On the other hand, the main idea to reduce the manufacturing cost was to combine some elements of studied part, so the price of producing a single adjuster would be lower. Then, this idea was divided into two: combining the main shell with the big cylinder and combining the main shell with the small cylinder.

After doing this brainstorm, a comparison between the remaining purposes was performed. The tool used to this function was the Pugh Matrix, which is a useful table to contrast these ideas looking at what customer requirements meet each one of them:

<b>Customer Requirement</b>	<b>Weigh</b>	<b>Visor</b>	<b>Change Form</b>	<b>Assembly 1</b>	<b>Assembly 2</b>
<b>Easy to Use</b>	6	1	0	0	0
<b>Low Cost</b>	7	-1,5	-1	1,5	2
<b>Durability</b>	5	0	0,5	0	0
<b>Mobility and cleaning of lenses</b>	6	2	0,5	0	0
<b>Fragility</b>	5	-1	1	0	0
<b>Score</b>		<b>2,5</b>	<b>3,5</b>	<b>10,5</b>	<b>14</b>

Therefore, the chosen idea to be developed was assembling the main shell with the small cylinder. This combination would presumably allow a higher decrease in the production costs than the other assembly, as introducing the small cylinder in the new assembling would be tougher than introducing the big one. The first CAD model of this idea is the next one:



Continuing with the process of implementation of this new part, a first physical prototype was manufactured in the Innovation Studio of the Mechanical Engineering Building in the University of Illinois to prove its functionality. The dimensions of this first try were not accurate as the small cylinder did not fit in its cavity present in the big cylinder, so the new part had to be redesigned again and it was printed in 3 scales: 100%, 102% and 104%. Finally, the best version was the redesigned part printed at a scale of 100%, so this piece was selected to be the final version of the new lenses adjuster:



#### 4. Conclusions

All this process and redesigning would have no sense if a final comparison between the original and the new product was not carried out. Because of this, a final contrast between the two products will be developed.

First, both assembling times for the old and the new version of the whole magnifier was calculated. While it took 94 seconds to produce the previous version, the redesigned one took 90.2. This difference in this variable will bring clear benefits to YOCTOSUN. Recalling the estimation of 25,000 units of magnifiers sold per year, the total assembling time per year amounts to  $25,000 \times 94 = 2,350,000$  seconds. With this number, the new total units produced per year can be calculated:

$$\frac{\text{Total assembling time in a year}}{\text{Assembling time for the redesigned product}} = \frac{2,350,000 \text{ seconds}}{90,8 \text{ seconds}} = 25,881 \text{ units}$$

Therefore, as almost 900 magnifiers more per year can be produced, YOCTOSUN has two options with this improvement, which can give YOCTOSUN plenty of possibilities to gain competitive advantage against its competitors.

Furthermore, analyzing the production costs (again with the help of *APriori*. Here are the results of the estimation made by this program for the new lenses adjuster:

Component	Total Variable Costs	Piece Part Cost	Fully Burdened Cost
Main Shell	0.07	0.14	0.16
Small Cylinder	0.13	0.22	0.24
Sum of the two parts	0.20	0.36	<b>0.40</b>
Redesigned part	0.08	0.14	<b>0.17</b>

Thus, a clear cost reduction has taken place: producing the two components separately costed \$0.40, while producing one unit of the redesigned part costs \$0,17, so \$0.23 would be saved for every magnifier that is being produced. Therefore, as 25,000 units are sold per year, this would be the amount saved (assuming that they are not lowering the price) by YOCTOSUN with this change:

$$\text{Amount saved} = 25,000 \text{ units} \times \$0.23 = \$5,570$$

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# 1. Disassembling of the product. Bill of materials.

The head mount magnifier is a product that is sold only by Amazon. This is why the description of the item that appears in Amazon is which is going to be showed here:

“The YOCTOSUN LED lighted head magnifying visor is a fully adjustable magnifying glasses with ultra-clear optical quality lenses designed specifically for seniors, hobbyists and professionals. Perfect headset magnifier for close up work like dentists, electricians, jewelers, sewing, crafts, beauty and painting”.

## 1.1. Disassembling of the product

In order to give an idea of the components of the head mount magnifier, some pictures were taken in the process of disassembling the product.

First, the available photos of the product on Amazon are a good reference for the outside view of the magnifier:



Figure 1: General view of the magnifier



Figure 3: Back view of the magnifier



Figure 2: Side and front view of the magnifier

The first step for disassembling the magnifier is separating the temples from the main shell. This has to be hand-made as there are not screws that join these two parts, and it has to be done with care because the grip that holds the temples is very tiny.



*Figure 4: Disassembling of the ear temples*

Next, the rubber pad can be easily disassembled by hand (use of nail may be needed):



*Figure 5: Disassembling of the rubber front pad*



Then, the nose adjuster and the inside top that guard the electrical cables from outside are joined with the small narrow screws and one large narrow screw, respectively; so, the use of screwdrivers is required.



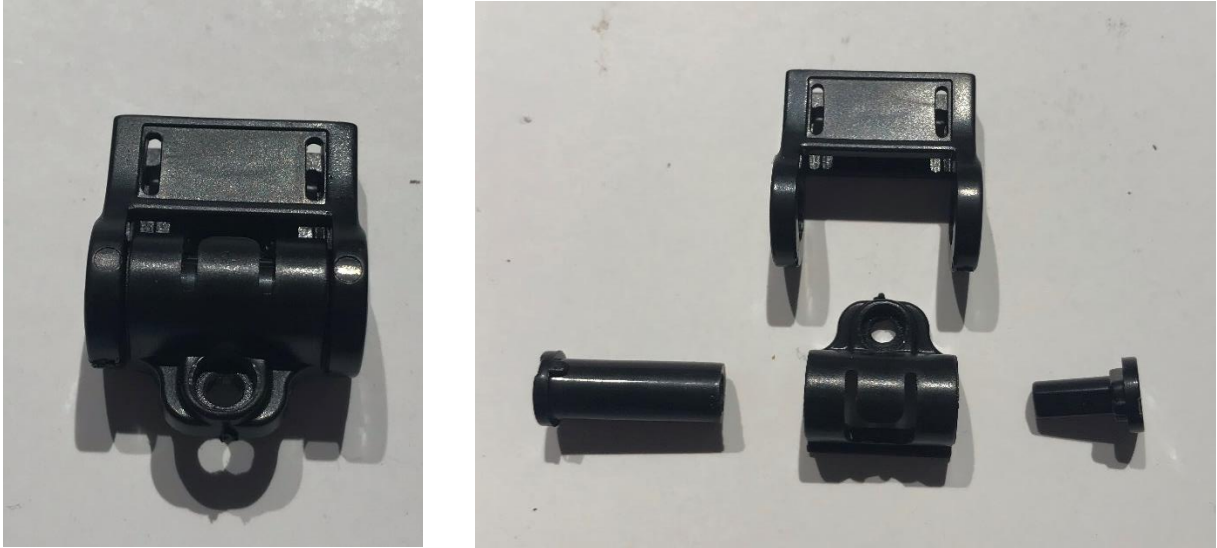
*Figure 6: Disassembling of the nose adjuster and disassembling of the inside top*

Moving now onto the lateral sides of the magnifier, two plugs join the main shell and the LEDs shell. However, those two parts will be never disassembled because they are joined by the electrical cables too.



*Figure 7: Disassembling of one of the cylindrical side plugs*

The next step is disassembling the lenses adjuster from the main shell, also with a screwdriver (in this case, it is joined by a small narrow screw). At the same time, the lenses adjuster is made up of four elements: the lenses adjuster main shell, the medium shell, the big cylindrical plug and the small cylindrical plug.



*Figure 8: Lenses adjuster assembled and disassembled*

Finally, although they are not part of the magnifier, it is appropriate to show the lenses and how they are connected to the magnifier by the lenses adjuster.



*Figure 9: Glasses assembled with the magnifier and the five different magnification glasses*

## 1.2. Bill of materials

After explaining the process of disassembling, the bill of materials shows in a clear way the material of which each part is made, the manufacturing process used and their quantity in the product. A photo of all the components together precedes this table to ease the identification of each of them.

Number	Part name	Material	Manufacturing process	Quantity
1	Main shell and electrical components	ABS Plastic and metal	Injection molding and sheet metal casting	1
2	Rubber front pad	ABS Plastic and rubber	Injection molding and extrusion	1
3	LED shell	ABS Plastic	Injection molding	1
4	Ear temples	ABS Plastic and rubber	Injection molding and extrusion	1
5	Hoops	ABS Plastic	Injection molding	2
6	Cylindrical side plugs	ABS Plastic	Injection molding	2
7	Inside top	ABS Plastic	Injection molding	1
8	Lenses adjuster main shell	ABS Plastic	Injection molding	1
9	Lenses adjuster big cylindrical plug	ABS Plastic	Injection molding	1
10	Lenses adjuster medium shell	ABS Plastic	Injection molding	1
11	Lenses adjuster small cylindrical plug	ABS Plastic	Injection molding	1
12	Small narrow screws	Low carbon steel	Purchased	2
13	Large narrow screws	Low carbon steel	Purchased	3
14	Small wide screws	Low carbon steel	Purchased	2
15	Large wide screws	Low carbon steel	Purchased	2
16	Nose adjuster	Metal and rubber	Sheet metal casting and extrusion	1

Table 1: Bill of materials

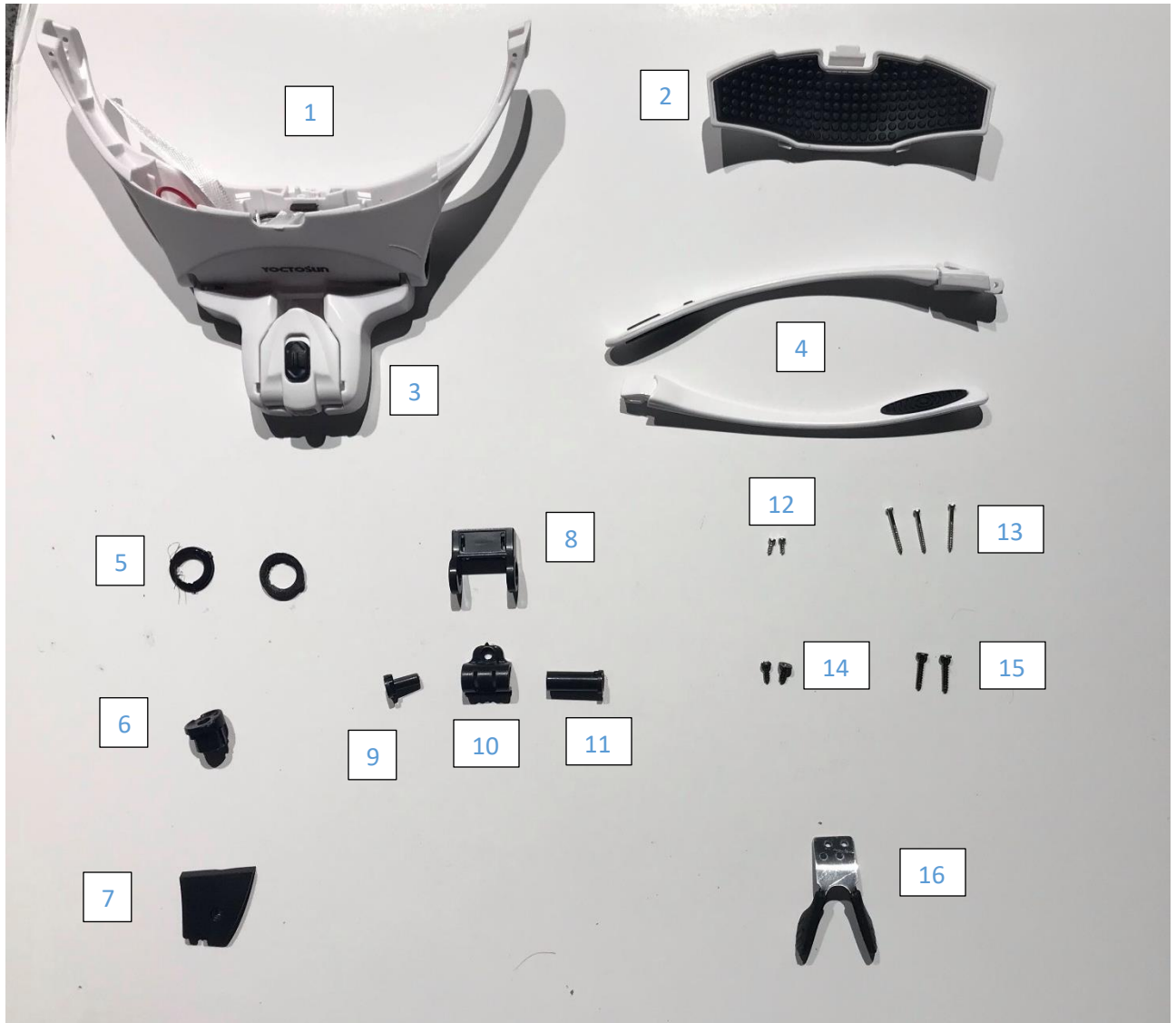


Figure 10: All the parts of the magnifier together

## 2. Technical Specifications and Market Data

### 2.1. Technical Specifications and Manufacturer

The manufacturer of the head mount magnifier is YOCTOSUN. In their website, they define themselves in the next way:

“YOCTOSUN is a registered brand approved in the United States and China. Our goal is to be the world most professional provider of office products. At present, our major product are YOCTOSUN magnifiers, microscopes and YOCTOSUN gift pens”

In the manual provided by YOCTOSUN about their product, there are different technical specifications about this head mount magnifier:

- Dimensions: 216 x 155 x 66mm
- Weight with bracket (without lenses): 55.3 g
- Lens external specification: 95mm X 34mm
- 5 kinds of magnifications: 1.0X, 1.5X, 2.0X, 2.5X, 3.5X
- Focal Length of 5 lenses: 533mm (1.0X), 381mm (1.5X), 266mm (2.0X), 178 mm (2.5X), 152mm (3.5X)
- Minimum distance between lens and eyes on the slot: 45mm
- Maximum distance between lens and eyes on the slot: 65mm
- Maximum lens angle: 60°

Also, several features about the item can be found in the same manual:

- Lens surface is treated with strengthening process to reach surface hardness of H5 degrees.
- Extended Gacoing lenses in the lens is arranged below the middle, has opened a “U” shaped notch, this design can make the eye lens and the distance closer, make the eye field wider, observe the object more easily.
- Movable lens slot is used to adjust the focal length between lens and object, and the distance between lens and eyes.
- Lens part and bracket part adopt internal/external meshing structure to avoid falling-off in time of viewing and reading. Both parts can be repeatedly turned over when they are not used temporarily, with solidness and durability.

- Nose bridge holder adopts stainless steel/soft glue gluing secondary injection molding. This holder can be adjusted freely according to the nose bridge shapes of different users.
- Previous version MG9892B eyeglasses magnifier adopts button batteries, which has low capacity, short durability and needs frequent replacement. However, this upgraded version adopts three AAA batteries, therefore, battery capacity is greatly increased to realize battery life 20 hours longer than previous version.
- Lens angle and LED light source irradiating angle can be adjusted to ensure accurate irradiation of light source on the surface of the viewed object, making it more convenient in use.
- Common bracket-type eyeglasses magnifier can fall off easily during use because lens and LED light source parts are quite heavy. This product can solve such problem completely. If this magnifier needs to be worn for long time, it is advised to change bracket into headband state, which can make work comfortable.

## 2.2. Market Data

In order to make an accurate analysis of the magnifying glasses market, and since there are a lot of different products (from a simple old magnifying glass to the product that is being analyzed), it is pertinent to show a study over the optical market and see how this affects the magnifying glasses market.

The optical market is steadily increasing due to the continuous use by a big part of the population of electronic items. This causes people strain on eyes and to increase their myopia and, therefore, the demand of glasses and contact lenses does not stop to go up. This trend can be seen in the next graph from 2016:

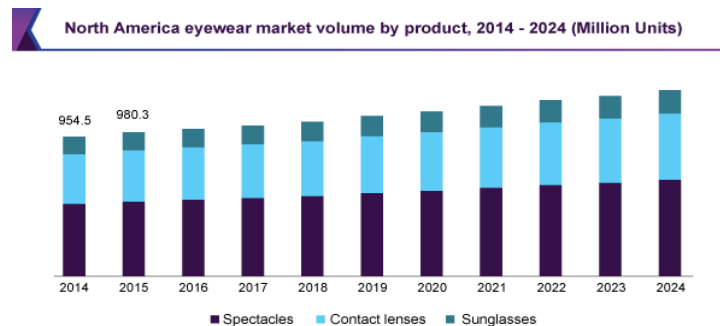


Figure 11: North America eyewear market volume

Furthermore, lenses prices are becoming more and more affordable as new techniques of fabrication are being developed, which makes this market more attractive and accessible to buyers. In this way, people are also carrying more about their appearance, so contact lenses prices are gaining market share to the glasses.

Another factor that ensures this rise of the market is the increasing life expectancy and the fact that now the population lives more, preferring the prescription-based spectacles to tackle visual deficiencies and cure refractive errors. For example, the National Health Interview Survey (NHIS) makes yearly a survey interviewing 35,000 old-age American people and asking for their availability to see. Some of the results of 2015 survey are shown in the table below:

<b>NHIS Year</b>	<b>Estimated population with vision loss, ages 65+</b>	<b>Estimated population who are blind ages 65+</b>
2014	6.1 million (13.5%)	350 thousand (0.8%)
2013	6.2 million (14.3%)	420 thousand (1.0%)
2012	5.3 million (12.7%)	410 thousand (1.0%)
2011	5.4 million (13.5%)	340 thousand (0.9%)
2010	5.4 million (13.9%)	400 thousand (1.0%)
2005	6.0 million (17.3%)	420 thousand (1.2%)
2000	5.7 million (17.4%)	400 thousand (1.2%)
1997	5.8 million (18.0%)	381 thousand (1.2%)

*Table 2: Population 65+ with vision loss and blind*

Some of the major market players include CooperVision, Luxottica Group S.p.A, Bausch + Lomb Inc., CooperVision, Fielmann AG, and Safilo Group S.p.A. These big sellers have managed to offer a wide range of products taking care about the quality. Their vertical integration planning and their innovative distribution channels caused them to lead clearly this market. Furthermore, these brands have benefited from the sophistication of the contact lenses market.

Talking now about regional insights, Europe is leading this market. The revenue last year was USD 35 billion, due to the big demand in this region for premium sunglasses to protect their eyes. Asian Pacific region represents a considerable market share on the overall market, and it is expected to grow over 30% in the next few years. The changing lifestyle and the lower prices seem to be key facts in the growth of this region. The North America market is also expected to witness

a growth in the near future. Rising acceptance of eyewear (badly seen in a not too distant past). The worldwide distribution of the market is showed in the next graph:

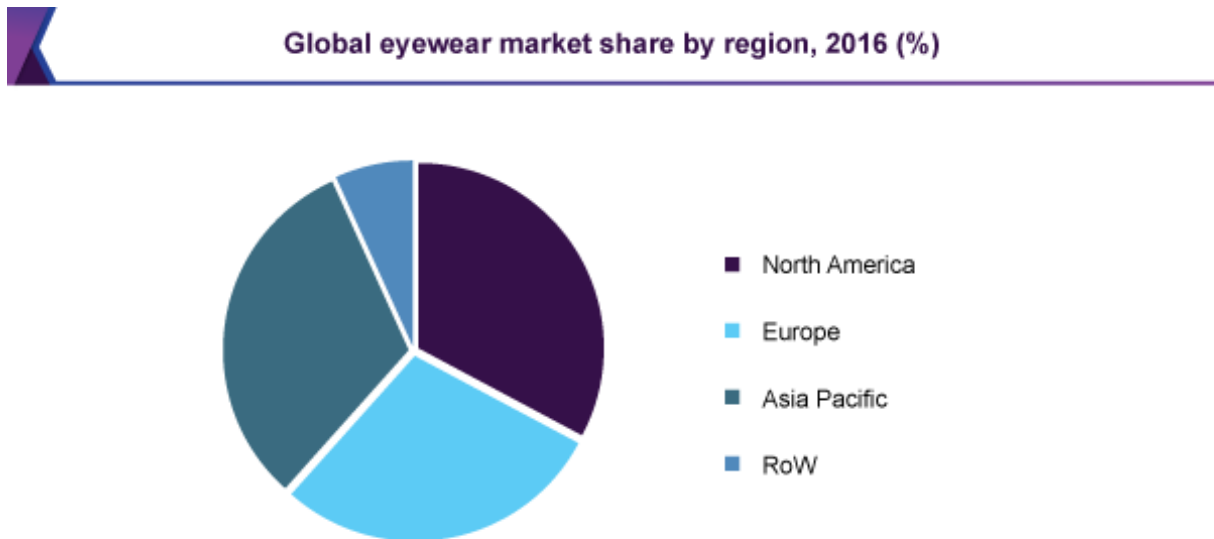


Figure 12: Global eyewear market share by region

As it just has been showed, the optical market is increasing owing to different independent facts and in most regions in the world. Therefore, if some bet must be made about the magnifying glass market, the most logical it would be to state that is going to evolve in the same direction as the optical market. Another factor that helps to strength this idea is that most activities where magnifying glasses can be used are also being intensified. For example, as the economist Clare McAndrew outlines in *The Art Market | 2018*, released Tuesday by UBS and Art Basel, the global art economy grew for the first time since 2014 with \$63.7 billion in total global sales, a rise of 12% from 2016. Also, salaries for electrical technician (who also can require this product for their job) have increased until \$50,179 per year. So, it is pertinent to conclude that the magnifying glasses market is going to increase in the next few years.



## 3. Manufacturing Cost and Design for Manufacturability Techniques

### 3.1. Estimation of Manufacturing Cost

Manufacturing costs are the costs of materials plus the costs to convert the materials into products. From an economic point of view, once they are calculated, they are used for inventory valuation and for the calculation of the costs of goods sold, which is then used to know the gross profit of a firm.

Manufacturing costs are usually divided into three categories. The first of these three is direct materials, which are the materials used in the construction of a product. The second is direct labor, which is that portion of the labor cost of the production process that is assigned to a unit of production. Finally, manufacturing overhead costs are applied to units of production based on a variety of possible allocation systems, such as by direct labor hours or machine hours incurred (for example, salaries, equipment repair parts or depreciation factory assets).

In the case of the magnifier, it is difficult to estimate with a high accuracy the exact manufacturing cost. Nevertheless, some approximations can be made. Concerning the products where plastic injection molding is the predominant technique used, manufacturing costs usually account for one third of final total sales of the product. The product is sold at \$16.79, so this could lead to the idea that the manufacturing cost of each head mount magnifier is \$5.5.

However, a note must be done regarding this. Probably, the overall manufacturing cost of all manufactured items is in fact around one third of total sales. But the cost of one single object depends on the sales volume that the company has. The cost of manufacturing one the first magnifier is, for sure, bigger than \$5.5, but as machines working on a big scale and the efficiency of the workers come into play, the manufacturing cost is reduced.

### 3.2. Identification of Design for Manufacturability Techniques

The head mount magnifier that is being analyzed went out to the market at January 2017. This makes clear that is a new and innovative product. Also, it is not the first version of the item. Therefore, some Design for Manufacturability (DfM) techniques can be found in the head mount magnifier.

The first and most evident of these techniques that has been used is plastic injection molding. Surfing through the Amazon page, magnifying glasses made up of metal can also be found. This does not mean that the competitor that is selling those glasses did not think about employing plastic injection molding in their product; they probably preferred to continue using metal because it is a better material for some of the uses for the magnifying glasses (for example, metal magnifying glasses provide a better fastening for sure, which can be a primary requirement for electrical tasks). Anyway, YOCTOSUN must have thought that the reduction in cost that comes from using plastic injection molding should be worth it, so this is the first Design for Manufacturability technique that was found.

Besides, the use of plastic injection molding not only leads to a cost reduction but also implies a lower weight of the item. This factor can be very appreciated by the users of the magnifier as the tasks for which it has been designed usually require a long time of wearing it, so a lower weight can make these tasks much more comfortable.

In addition, the rubber pad for the face is also a result of a DfM technique. Probably, in previous versions of the project that part was made up of plastic (as all of the shell of the magnifier), and users of the product (via reviews in Amazon) showed their discontent about the discomfort that this topic implied. For example, if a painter is trying to paint a detail and the product is not comfortable to his head, he is not going to value the magnifier the same way as if he can be completely concentrated in the painting.

# 4. Quality Function Deployment (QFD)

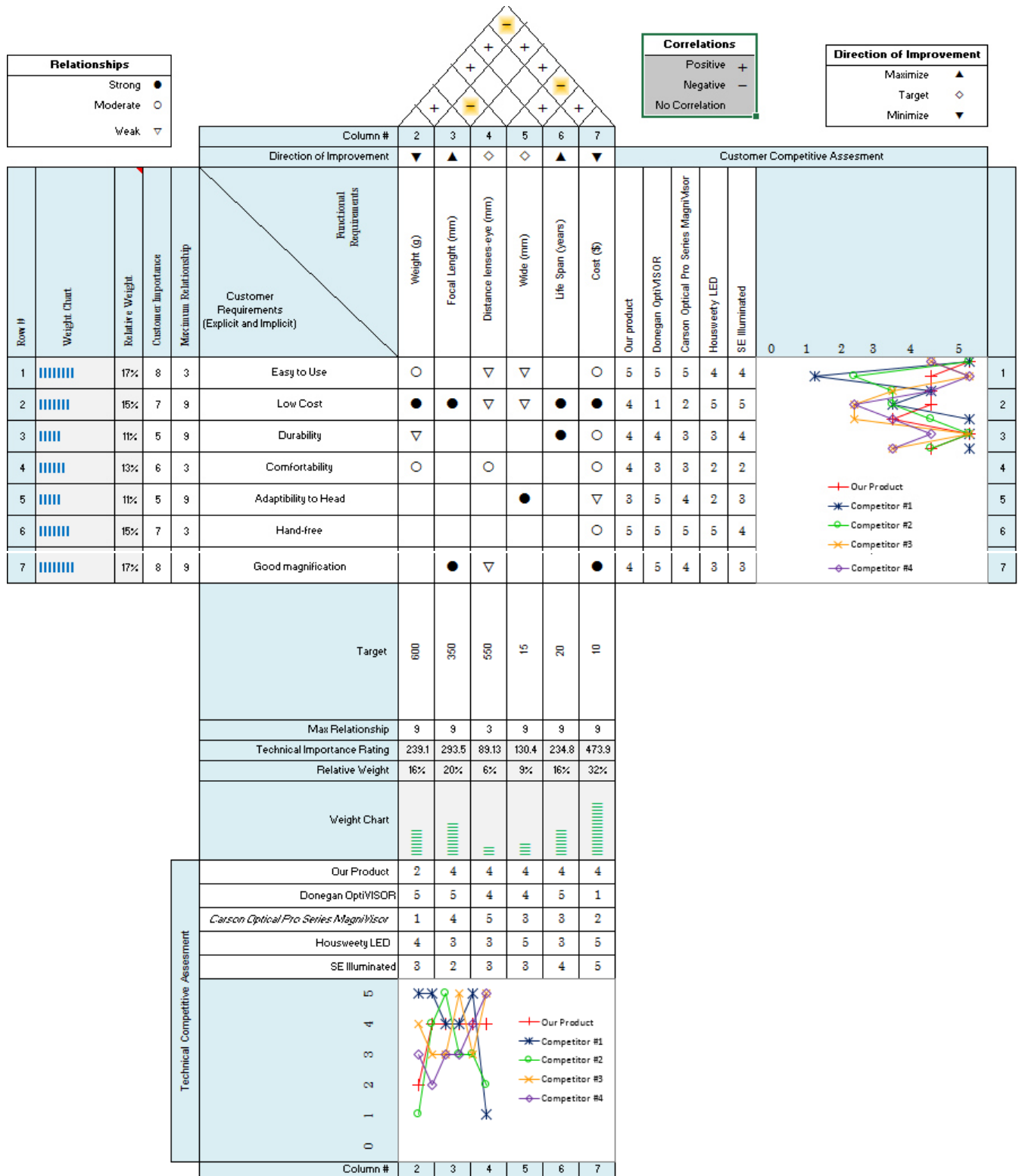


Figure 13: Quality Function Deployment

The Quality Function Deployment (QFD) is a structured approach to defining customer needs or requirements and translating them into specific plans to produce products to meet those needs. In other words, this mechanism means understanding the “voice of the customer”, listen to all the opinions, the complaints and the suggestions that they may want to do.

Hence, the QFD tries to congregate all these requirements with the characteristics of the studied object, so this perception of the customer desires can be matched to all the possible features of the product. Those are usually written after reading all the opinions, so the analyst can know the customer functional expectations of the product. Furthermore, a relative weight is given both for the customer and the functional requirements. It is important that these characteristics can be measured, so an objective (numerical) conclusion can be got.

In order to perform this, Amazon Customer Reviews has been a very useful tool as this product is only sold online only in this platform. Looking and analyzing the different feelings of the users, a first idea about the aspects that the YOCTOSUN magnifier may have to improve can be sketched. For example, the affordable price or the good magnification were aspects positively considered between customers. Another factors like comfortability or durability were also frequent commented.

Once the customer requirements are clear, measurable functional requirements can be found so that they can meet with one or more requirements. For example, it is clear that it is going to be a functional requirement of “Cost”, which logically is related to all the customer requirements. Other measurable features of the magnifier that cannot be missed are focal length (which is strongly related to the requirement of “Good Magnification”, or the weight of the magnifier, that has a great considerable influence in the comfortability or the magnifier price.

Finally, the main competitors of the studied item must be included in the matrix so it can be seen the place that the product is in the market and what advantages make the YOCTOSUN magnifier to be differentiated from its competitors. After analyzing its major competence, it seems that it is bought because its good value for money.

## 5. List of Customer Requirements

After rethinking about the product and seeing several more opinions in Amazon Reviews, all of these requirements can be set in order to please the needs of the customers:

Customer Requirement:	Customer Importance:
1. Comfortability / Adaptability	
1.1. Adaptability to ears .....	6
1.2. Adaptability to head .....	5
1.3. Adaptability to nose .....	5
1.4. Smooth surface to face .....	8
2. Lenses	
2.1. Magnification range .....	8
2.2. Focal length .....	8
2.3. Cleaning cloth to clean the lenses .....	7
2.4. Mobility of lenses .....	8
3. Cost	
3.1. Cheap enough to be worth buying .....	7
4. Aesthetics	
4.1. Aesthetically pleasing .....	5
5. Size	
5.1. Lightweight .....	7
5.2. Easy to keep in small bag .....	6
6. Stability	
6.1. It does not wobble while doing tasks .....	8
7. Light	
7.1. Stability of batteries .....	8
7.2. Power of LEDS .....	8
7.3. Mobility of LEDS .....	7
8. Life expectancy	
8.1. Enough to make it worth buying .....	7

## 6. Direction for Improvement (updated QFD)

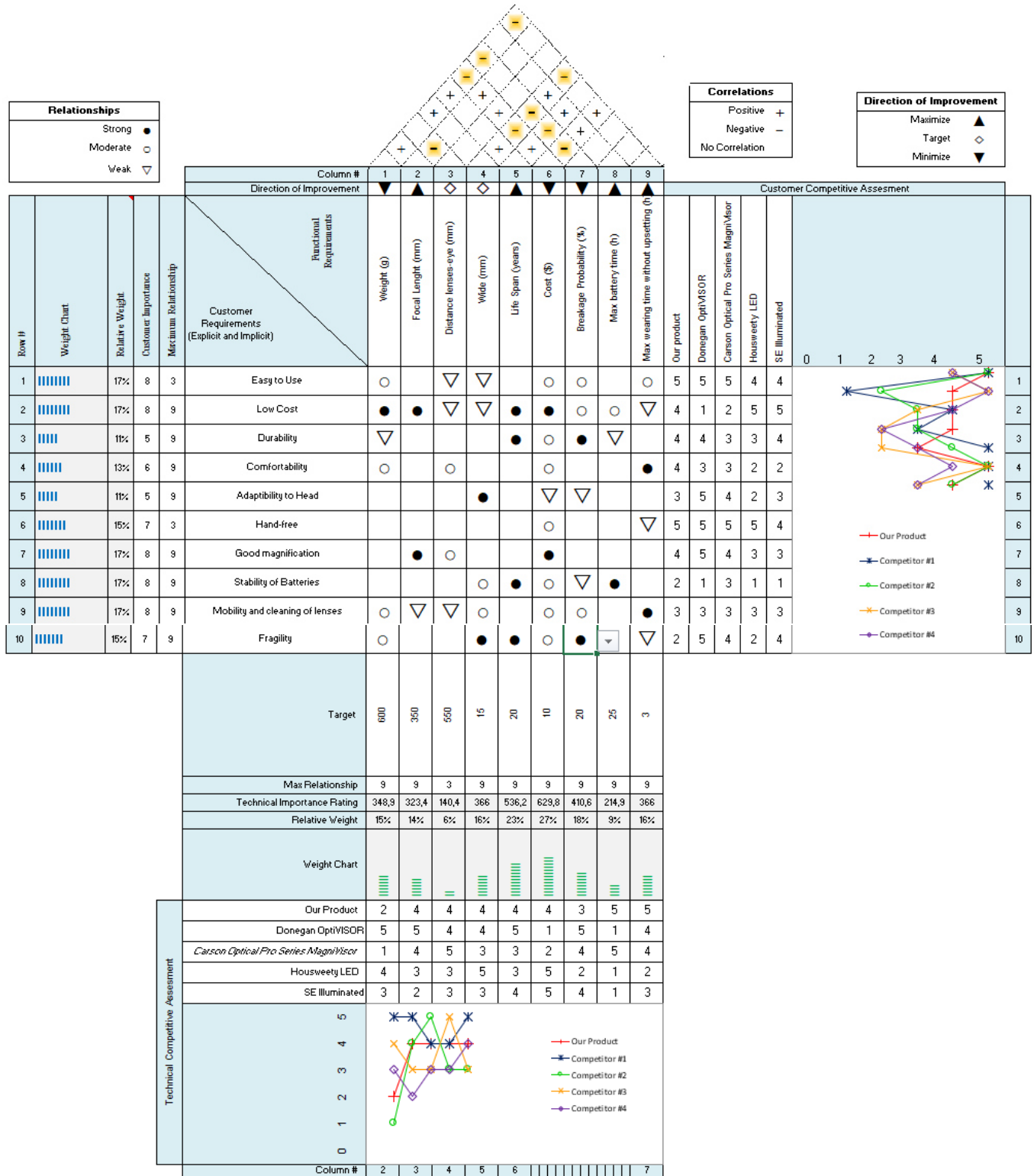


Figure 14: Updated Quality Function Deployment

After doing a more detailed research in question 5, it is clear that important customer requirements such as the stability of the batteries or the mobility of the lenses were not included in the first Quality Function Deployment in question 4. In the updated QFD of question 6, these requirements were included to have a wider view of what customers expect from this product.

In the case of the head mount magnifier of YOCTOSUN, an important requirement mentioned a lot in the Amazon reviews was that the batteries did not fit well in the cavity, so it was a hard business to get to turn on the LEDs:

“I was unable to get the batteries into their compartment! One of the spring contacts for a battery was pointing slightly downward and no matter how I gently tried to position it properly while also inserting it, the battery never would go flush into the compartment. The battery compartment closure piece would not snap into place. I had several people attempt this and no one could accomplish this first step.”

Another requirement that had not been considered was the mobility and cleaning of the lenses. This was also a common complain among the buyers of the product in the Amazon reviews. They criticized that they constantly needed to take off the magnifier to clean the lenses, dirtying them and losing an appreciable amount of time. Last, the high fragility of the temples was a problem because the probability of breakage is high, while that of its competitors seems to be less worrisome.

In the same way, some functional requirements (or quality characteristics) have been added. For example, in the first QFD, the probability of breakage had not been taken into account, when it is an important factor to contemplate, and also a good measure of the requirement of fragility. Likewise, maximum battery time was a characteristic that has been included. In this case, the Amazon reviews remarked (if the batteries finally fit in their space) that the duration of the batteries was a good factor to keep in mind when buying the product. Finally, some of the customers pointed out that the magnifier wobbled a lot while wearing it, loosening and making almost impossible to concentrate in the required task. This is why a characteristic called “maximum wearing time without upsetting” was included, in order to meet this complaint.

## 7. Areas to concentrate design efforts

With all this background about the changes in the QFD in mind, now it is time to see which areas are the most suitable to concentrate the design effort in, in order to achieved improved market share based on design for manufacturability.

Therefore, looking at the customer requirements with highest importance, the aspects that customers worry care more about are the ease to use, a low cost, good magnification, the stability of the batteries and the mobility and cleaning of the lenses. Similarly, the relative weight of the product characteristics shows that the most important ones are the cost (27%), the life span (23%), but others like breakage probability or the maximum time of use also play an important role.

After doing this analysis, the first area that comes to mind to concentrate the efforts is the cost of the product. A usual method to get to this goal is using plastic injection molding to build parts that are made up of metal (metal is always more expensive than plastic). Nevertheless, it looks that the designers of the head mount magnifier from YOCTOSUN have already thought about this issue, because it is almost all made of plastic, and it becomes a hard task to think to reduce costs this way.

However, another form that could allow a reduction cost (and, therefore, a lower price) could be improving the assembly, this is, combining two or more pieces in just one without losing functionality. This possibility will be later better analyzed.

Another area in which efforts could be focused is the cavity for the batteries, due to the critics about this issue by the buyers of the magnifier. A way to solve this problem could be to design reliefs inside the cavity so that each pile has its space, so they would have less chance to be displaced while using the product. Furthermore, it would be easier to detect if there is just one battery that is not working than in the actual model.

Besides, since cost reduction seems a difficult goal to achieve, a good idea would be to try to improve some characteristics of the product maintaining the same cost, in order to meet some of the requirements. Hence, as comfortability (and thus, maximum wearing time) is a concern among users, a good idea may be trying to make the head strap more comfortable (maybe adding some smooth material), which would not require almost any investment but could please some needs of the customers.



Finally, it would be interesting to see if there is a way to improve the requirement of mobility and cleaning of the lenses. It is true that this product was equipped with a cloth to clean the lenses, but users of the magnifier (as it was commented before) seemed upset about this issue because they constantly got dirty and they could not concentrate in their tasks if they had to clean them every 5 minutes. Designing something to avoid this issue could be a good idea too.

## 8. Product Design Specification (PDS)

After elaborating and improving the Quality Function Deployment and identifying the most accurate areas to concentrate the design effort, a Product Design Specification is needed. This is a statement of how a design is made (specify the design), what it is intended to do, and how far it complies with the requirements. Several points will be listed in order to make the best possible analysis:

- **Performance:** the main function required for the magnifier are, as it has been stated in previous points, is that it provides a good magnification with a comfortable wear so that the user can concentrate on the task that it is being done, so the new model should improve this need in some way.
- **Environment:** the magnifier is packaged in a quite careful way due to the transportation that is required to make it get to the customer. Also, it is convenient that the user is aware about the fragility of the temples, because if they are disassembled, there is a high chance of breaking the plastic parts that hold them.
- **Life expectancy:** although this point depends on the task that will be performed, and the periodicity with which it will be used. However, no one who buys this item expects that it lasts less than a few years.
- **Maintenance:** at first, no constant maintenance seems to be required with this product. However, as it counts with an electronical part (LEDs), it may need that in case that this part stop working.
- **Target product cost:** since the product has been sold in Amazon for two and a half years, it looks like the total sales meet the costing of the product. Nevertheless, to know it exactly, data like the number of workers or the machines acquired by the company would be needed.
- **Availability of components:** since providers of YOCTOSUN are not known, it is impossible to know if YOCTOSUN has any problems with the suppliers. Anyway, the most important components to care about are the plastic shell and the lenses, since there are more manufacturers and providers of screws than that of those parts.
- **Packaging:** packaging is clearly required both for the magnifier and for the lenses. Current packaging does not seem to require changes since magnifier and lenses usually get to the customers in a good condition.

- **Transportation:** as it is a product distributed by Amazon in the United States and China, YOCOTSUN depends on this company to ensure a proper transportation. In the case of the US, the item is taken to buyers' home in the Amazon trucks, which depart from all the numerous Amazon warehouses.
- **Quantity:** as there are almost 1,500 verified reviews in Amazon (this is, customer must have bought the product to give a review), a good estimation of the number of magnifiers sold is 4,500 (one review every three clients). Since this version of the magnifier has been sold from January 2017, a good estimation could be that around 25,000 units of this item are sold per year. Although this cannot be considered high volume production, it cannot be taken as a very small production either.
- **Manufacturing facilities:** although YOCTOSUN depends on the contract with current manufacturers, it would be an interesting option considering manufacturing its own components and guide the business on a larger scale without depending on anyone (however, it should increase production level to contemplate this).
- **Size and weight:** the size and weight of the magnifier it is not a problem for its transportation. Anyway, the smaller the size, the bigger the number of products that can be transported at once.
- **Aesthetics and finish:** the head mount magnifier of YOCTOSUN gives a good first impression to the customers. White color gives an elegant and modern appearance to the product, and surface finish is accurate at first sight.
- **Materials:** in the case of the magnifier, three materials are required to build it: plastic, metal and glass. While the two first are more common and easier to get, the type of glass must be chosen with care in order to get a good magnification.
- **Product life span:** optical market is a very changeable and unpredictable one, and products like YOCTOSUN's magnifier are frequently superseded by others more modern. YOCTOSUN will need to keep updated and pay attention to customers' reviews to continue being competitive.
- **Standards and specifications:** as the US and China are the only countries where the product is commercialized, standards of those two countries apply. Besides, internal standards of Amazon also play a role in the distribution of the product.

- **Ergonomics:** the magnifier is an ergonomic product as it is easy to handle, easy to wear and easy to use.
- **Quality and reliability:** as the market has several competitors with different prices, customers expect different time of failure depending on the quality of the product (inversely proportional to the price). In the case of YOCTOSUN's magnifier, buyers expect a good performance, but it would not be a surprise if it gets broken.
- **Shelf life:** in this point, it should be noted the use of batteries, that are the only perishable components of the item.
- **Processes:** manufacturing processes that could be highlighted here are plastic injection molding and rolling for the screws.
- **Safety:** the magnifier is an item that must not endanger the user in any case. Anyway, LEDs should not be used for a long time so as user's sight is not damaged.
- **Company constraints:** as it was stated on the first point of the project, the magnifier is the main product that YOCTOSUN commercialize, so it must not have any company constraints.
- **Market constraints:** the market of magnifiers is a competitive one as it is in continuous technological advance which requires sellers to keep updated at the same time that they offer competitive prices.
- **Patents:** YOCTOSUN is the owner of the patent of this head mount magnifier so there would not be any problem in this field.
- **Product liability:** in case that there is any unintended consequence of production, operation or use, it would be responsibility either of YOCTOSUN or Amazon. If these were manufacturing consequences, it would be YOCTOSUN's responsibility while if these were due to any damage, Amazon would be responsible.
- **Installation, operation:** the magnifier is provided with the five different magnification lenses, three AAA batteries and a cloth to clean the lenses when necessary.

## 9. Design for Manufacture and Assembly (DfMA) Analysis

Once the customer requirements and the product characteristics haven been properly analyzed, and after making conclusions about that and forming the Product Design Specification, it is pertinent to do a Design for Manufacture and Assembly (DfMA) Analysis. This analysis is divided in two parts (as its name indicates): assembly and manufacture. The goal of this analysis is to find the most efficient way to get to the final product, regardless how complicated the process may be. In other words, try to minimize costs (labor, overhead and materials) to reach the highest possible profit margins.

So, at this point, it is time to examine more carefully how the magnifier of YOCTOSUN was devised. First, engineers of the company had to elaborate a Concept Design, where they had to decide how to articulate the function and form of the magnifier. For this, it is necessary to understand customer needs (as it was done in previous points of the project with the QFD).

### Sequence of Analysis

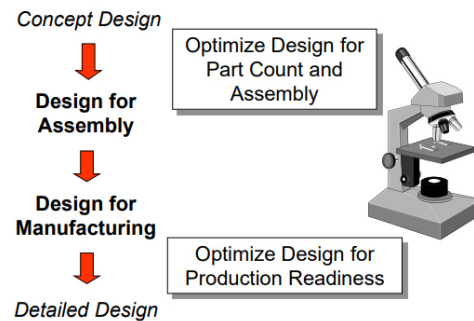


Figure 15: Sequence of analysis in design process

After that study, the next phase is Design for Assembly (DfA). Once that creators of the magnifier know that a rubber pad for the front, a cavity for batteries, a way to connect the batteries to the LED, temples for the ears... would be used to build the item, they require this process because it helps to reduce the cost of the future assembly (assembly costs account for 10-50% of total manufacturing costs).

A way to implement this is incorporating multiple functions into single parts, which allows to minimize the number of parts. In the case of YOCTOSUN magnifier, the front part of the main shell was needed to gain focal length as the distance lenses-eyes was increased. Instead of creating that part only for that function, the corresponding LEDs and their switch was installed there. Another part with more than one function is the main top with the rubber pad for the front. At the same time that it serves as a housing to close the cavity of the batteries and the electronic part, it fulfils a comfort function.

Other criteria used in DfA is to standardize to reduce part variety and the use of fasteners. The main shell of the magnifier is a big (related to the magnifier overall size) part and it does not need any screws of any other fastener. This allows the assembly process to be easier, faster and cheaper. Talking about the use of fasteners in the magnifier, there is a total of 9 screws. The large wide screws are necessary to prevent the housing with the LEDs from turning and falling. Two of the large narrow screws are used to assemble the temples for the ears, and the other one is needed to join the parts of the lens's adjuster, so their presence is required too. The small narrow ones join the nose adjuster to the main shell. Finally, one of the small wide screws is used to join the lens's adjuster with the main shell and the other to join the top that covers the electrical cables also to the main shell. So, it seems that no one of these screws can be eliminated as they all develop an important function.

Moreover, symmetry is also a factor that helps to reduce assembly costs. This almost completely achieved in the magnifier, since it needs to adapt to the consumer's head, which is symmetric too. There is the exception of the top that covers the electrical cables that translates the energy from the batteries to the LEDs, which is located at the right side of the product.

In addition, it is an item easy to assemble both for the manufacturer and the customer. As all the parts are fastened in one way or another to the main shell and there are almost no subassemblies (the only one is in the lenses adjuster with the three parts), it allows considerable savings in storage, inventory, ordering, etc. From the customer point of view, the only task that must be done is inserting the batteries and placing the contact lenses as the item is being used.

Once this analysis is made, it is appropriate to decide if there are some opportunities to combine or eliminate components so assembly costs can be reduced. Eliminating a component of the magnifier, its function should have to be dispensable, but every part develops an important function (either functional or protective). However, it is logical to think that there is a possibility to combine the main shell and the shell where the LED is located. This is because there are screws that join the both parts, which prevents the LED shell from moving (if this was not like this, there would not be a possibility to combine these two pieces). Another opportunity of combination could be manufacturing just one component instead of the three parts that shape the lenses adjuster.

Number	Part name	Material	Manufacturing process	Quantity	Combinable or eliminable
1	Main shell and electrical components	ABS Plastic and metal	Injection molding and sheet metal casting	1	Combinable
2	Rubber front pad	ABS Plastic and rubber	Injection molding and extrusion	1	
3	LED shell	ABS Plastic	Injection molding	1	Combinable
4	Ear temples	ABS Plastic and rubber	Injection molding and extrusion	1	
5	Hoops	ABS Plastic	Injection molding	2	
6	Cylindrical side plugs	ABS Plastic	Injection molding	2	
7	Inside top	ABS Plastic	Injection molding	1	
8	Lenses adjuster main shell	ABS Plastic	Injection molding	1	Combinable
9	Lenses adjuster big cylinder	ABS Plastic	Injection molding	1	Combinable
10	Lenses adjuster medium shell	ABS Plastic	Injection molding	1	Combinable
11	Lenses adjuster small cylinder	ABS Plastic	Injection molding	1	Combinable
12	Small narrow screws	Low carbon steel	Purchased	2	
13	Large narrow screws	Low carbon steel	Purchased	3	
14	Small wide screws	Low carbon steel	Purchased	2	
15	Large wide screws	Low carbon steel	Purchased	2	
16	Nose adjuster	Metal and rubber	Sheet metal casting and extrusion	1	

Table 3: DfA analysis for the magnifier parts

Now, to see if some of these two combinations is achievable, there are three frequently asked questions to measure assembly efficiency in DfA:

### Combination between the main shell and the LED shell

- Does the main shell move simultaneously with the LED shell? Since they are joined through screws, they are not allowed to move so they both are static components.
- Can the part be the same material as this other part? These two parts are already made of the same material (ABS plastic).
- Can the manufacturing method be the same for this part? The manufacturing method is already the same (injection molding).

The answer for these three questions invites to think that these both parts can be combined in only one. However, there is one reason why these two components are manufactured separately. The electrical cables that transport the energy from the batteries to the LEDs are much more accessible this way, so in case that the LEDs stop working or get broken, it is more feasible to identify the problem.

### Combination between the four parts of the lenses adjuster

- Do these four parts move simultaneously? No, the medium shell moves independently, so there is no possibility to combine these four components in just one. Anyway, as the main shell and both cylinders move together, the possibility of combining these three parts could still be studied.

After doing the Design for Assembly analysis, the next step is studying the Design for Manufacture. The purpose of this analysis (similar to the assembly one) is prevent unnecessary costs in the manufacture step. One distinction must be made at this point. For high volume production, this is a considerably relevant analysis to reduce costs in the manufacturing process. Nevertheless, as the YOCTOSUN magnifier is produced in low volume (25,000 units per year), this analysis loses some importance, but it must not be forgotten.

One way of prevention for unnecessary costs is using of standardized parts. In the head mount magnifier, all the screws were purchased in order to have the most possible standardize parts, which also leads to a reduction in assembly costs. If machines had to be bought by YOCTOSUN to build their own screws, earning profits would be a hopeless task.

Last, in the step of detailed design, refined plans, specifications and estimates would be created.



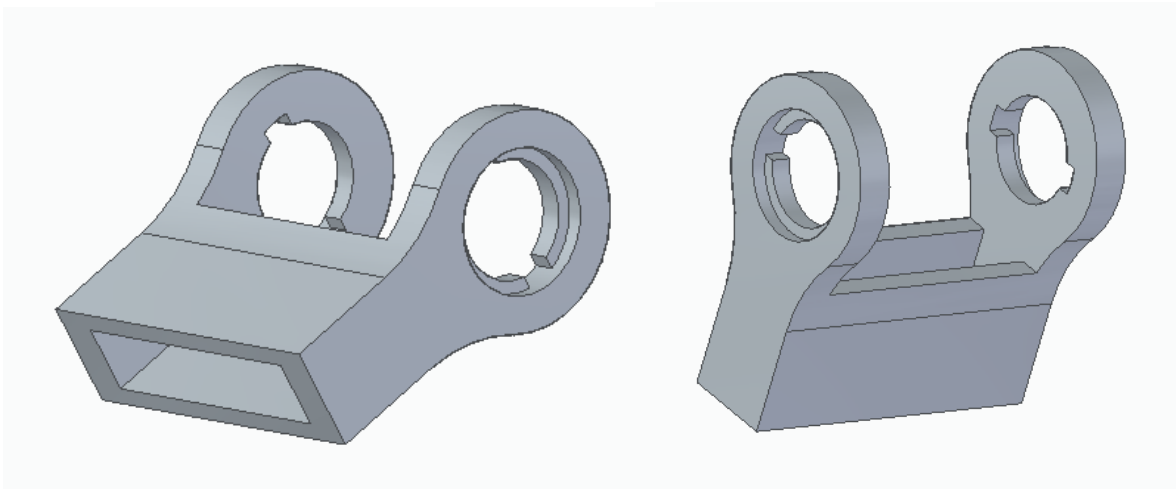
## 10. CAD modeling of the Existing Product

Due to the previous analysis that has been made, the part that has been selected to be investigated is the lenses adjuster. Different factors have been taken into account to choose it. First, although the three questions of the Design for Assembly rejected the possibility of designing just one part instead of those four, it would be interesting analyzing if there is a way to make some of these parts less detailed (and, therefore, save costs); or if it is possible to join, at least, two or three of them.

Furthermore, as it was stated in the analysis of the areas where concentrate the design effort, one of the most important requirements for the customers is the clean and mobility of the lenses: they do not like continuously raising and lowering the lenses while performing a task. In this way, if there is some accurate part to investigate in order to meet this requirement, this is the lenses adjuster.

Now, CAD modeling of the four parts of the lenses adjuster will be shown. The program used for this has been Solid Edge:

### Main Shell:



*Figure 16: General view of the main shell of the lenses adjuster*

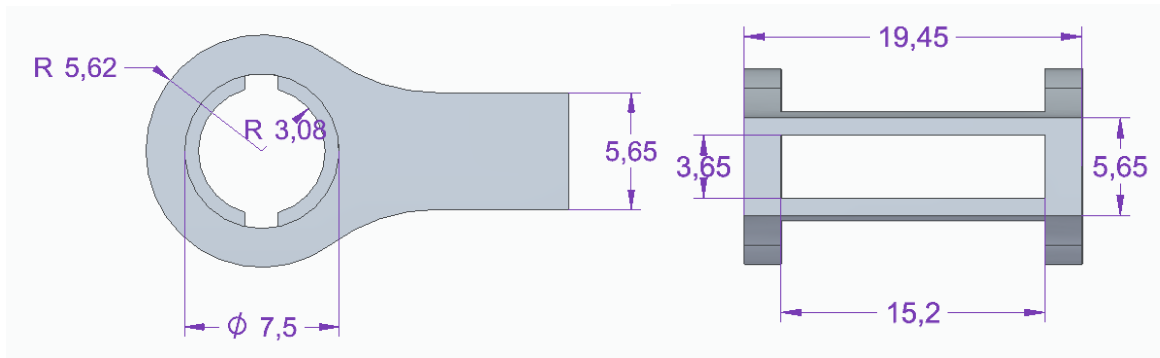


Figure 17: Dimensions of the main shell of the lenses adjuster

Medium shell:

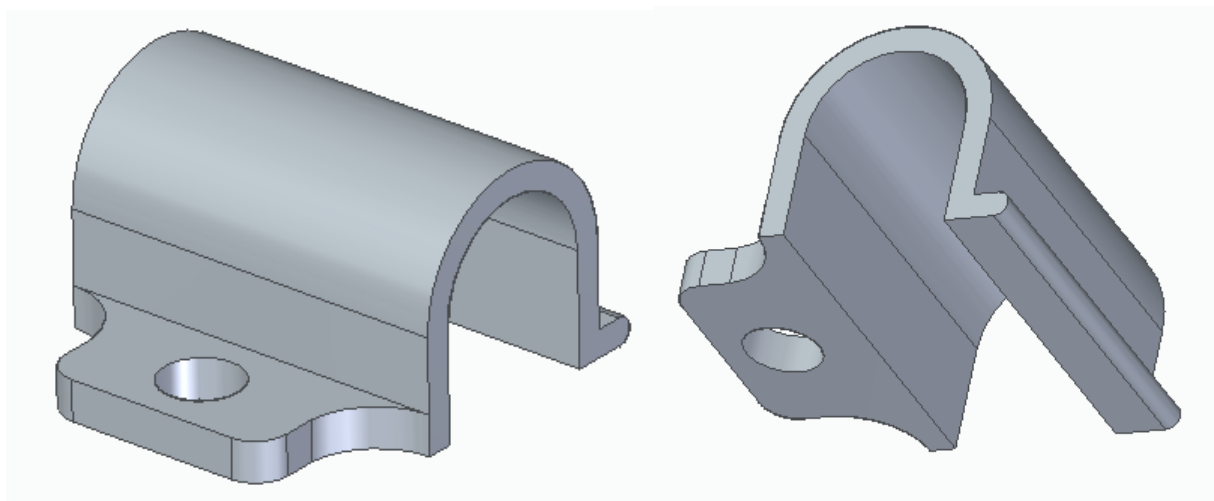


Figure 18: General view of the medium shell of the lenses adjuster

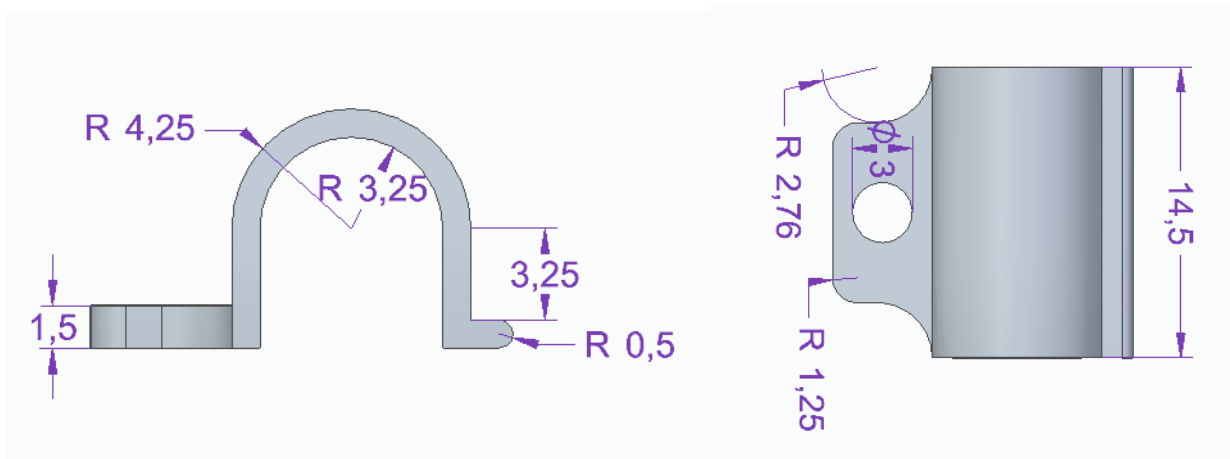


Figure 19: Dimensions of the medium shell of the lenses adjuster

Big cylinder:

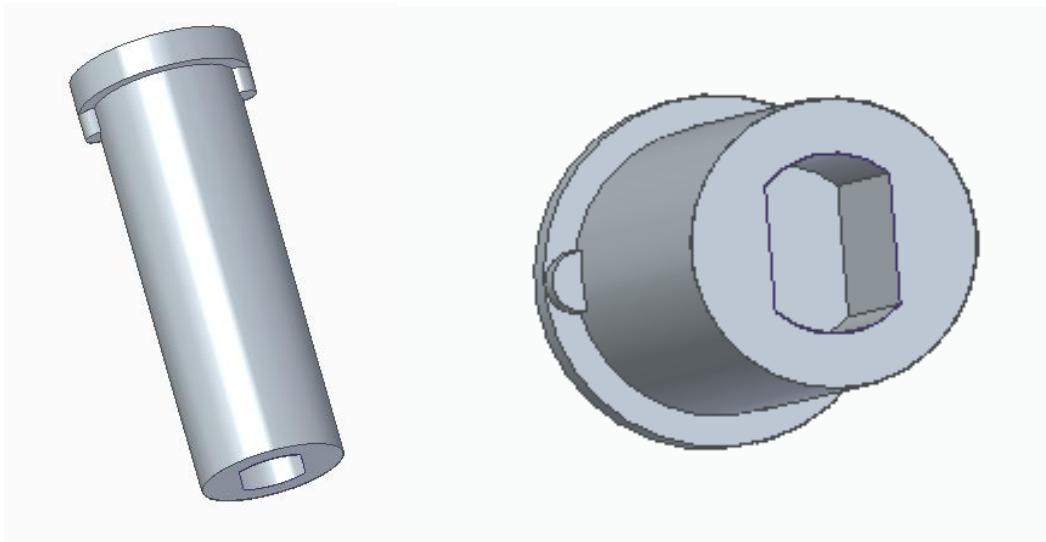


Figure 20: General view of the big cylinder of the lenses adjuster

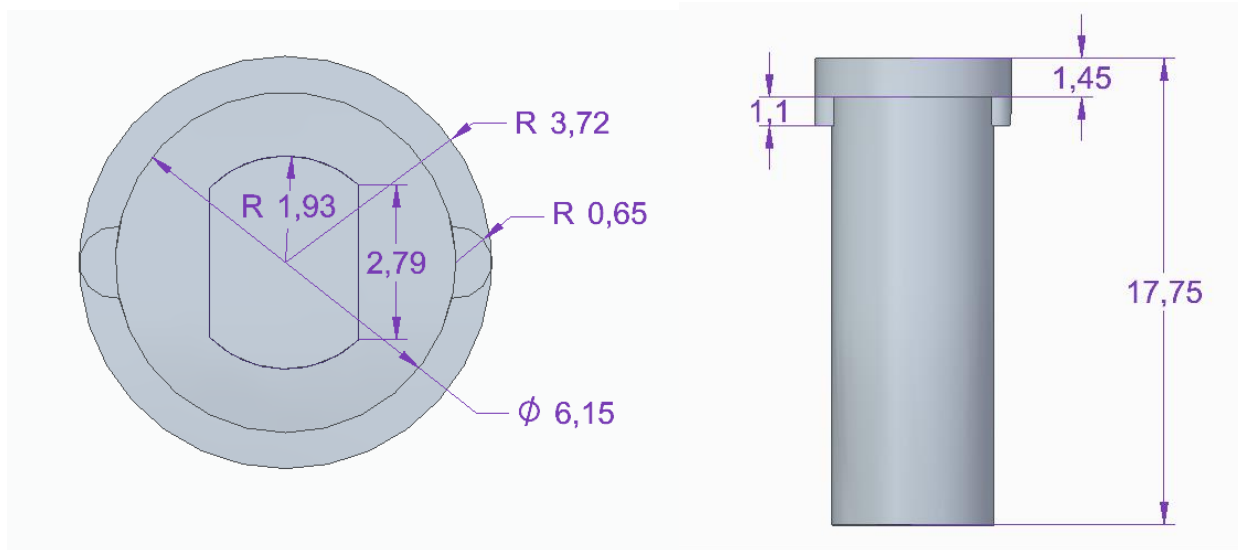


Figure 21: Dimensions of the big cylinder of the lenses adjuster

Small cylinder:

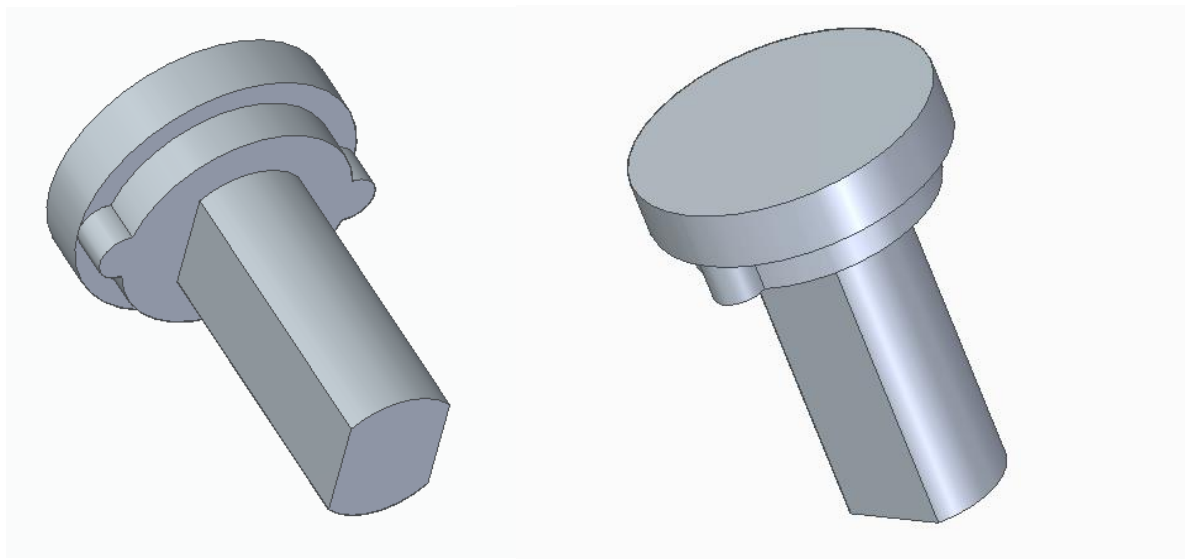


Figure 22: General view of the small cylinder of the lenses adjuster

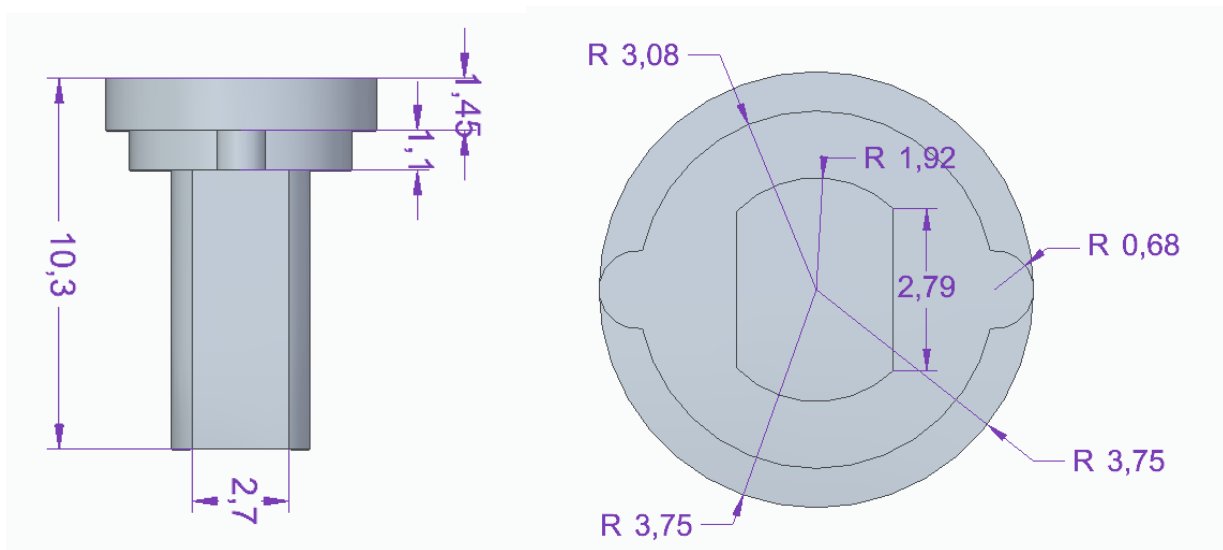


Figure 23: Dimensions of the small cylinder of the lenses adjuster

## 11. Manufacturing Cost Analysis of the Existing Product

Now that the lenses adjuster has been disassembled and the four parts of it can be studied in a proper way, it is time to estimate how much this concrete part of the YOCTOSUN magnifier costs to be produced. To perform this, the program *aPriori* will provide some costs details as the different pieces are introduced in it.

However, the program cannot provide a cost approximation if some inputs such as the material of the pieces, the number of pieces produced a year and the lifetime of the object are given. First, as it was stated in the first point of this report, the material for all these four parts is ABS plastic (which is the most affordable one and the most used for these type of products). Next, the number of pieces produced a year was estimated in 25,000 items per year, so this is the number that will be given to the program. Finally, since the magnifier is in a very changeable and variable industry, this version of the product surely will not last more than seven or eight years more. As it has already been in the market for two years, the lifetime that will be input in the program will be ten years.

Based on all this information, these are the results that *aPriori* provides about the costs of the pieces:

### Main Shell:

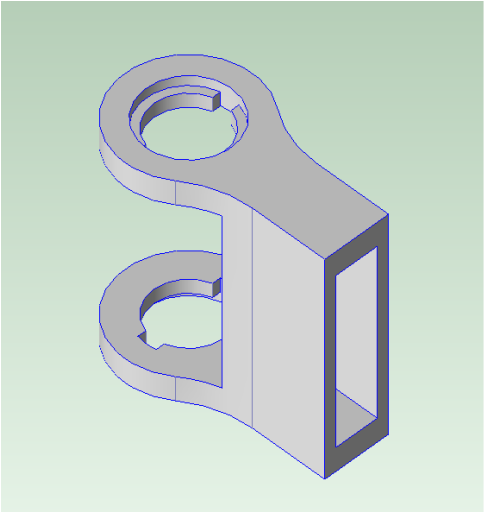
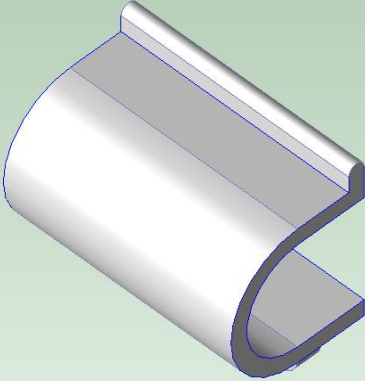
	<b>Variable Costs</b>	<b>Current (USD)</b>
	Material Cost	<0.01
	Labor	0.04
	Direct Overhead	0.01
	Amortized Batch Setup	0.02
	Logistics	0.00
	▲Other Direct Costs	<0.01
	<b>Total Variable Costs</b>	<b>0.07</b>
	<b>Period Costs</b>	
	Indirect Overhead	0.04
	SG&A	0.01
	Margin	0.00
	<b>Piece Part Cost</b>	<b>0.12</b>
	<b>Fixed Costs</b>	
	▲Total Amortized Investments	0.04
<b>Fully Burdened Cost</b>	<b>0.16</b>	
<b>Capital Costs</b>		
▲Total Capital Investments	15,273.77	

Figure 24: Main costs of the main shell

Medium shell:



	Current (USD)
<b>Variable Costs</b>	
Material Cost	<0.01
Labor	0.02
Direct Overhead	0.01
Amortized Batch Setup	0.02
Logistics	0.00
▲Other Direct Costs	<0.01
<b>Total Variable Costs</b>	0.05
<b>Period Costs</b>	
Indirect Overhead	0.03
SG&A	<0.01
Margin	0.00
<b>Piece Part Cost</b>	0.08
<b>Fixed Costs</b>	
▲Total Amortized Investments	0.02
<b>Fully Burdened Cost</b>	0.10
<b>Capital Costs</b>	
▲Total Capital Investments	8,654.63

Figure 25: Main costs of the medium shell

Big cylinder:



	Current (USD)
<b>Variable Costs</b>	
Material Cost	<0.01
Labor	0.11
Direct Overhead	0.04
Amortized Batch Setup	0.02
Logistics	0.00
▲Other Direct Costs	<0.01
<b>Total Variable Costs</b>	0.17
<b>Period Costs</b>	
Indirect Overhead	0.10
SG&A	0.02
Margin	0.00
<b>Piece Part Cost</b>	0.28
<b>Fixed Costs</b>	
▲Total Amortized Investments	0.02
<b>Fully Burdened Cost</b>	0.30
<b>Capital Costs</b>	
▲Total Capital Investments	8,168.90

Figure 26: Main costs of the big cylinder

Small cylinder:



Figure 27: Main costs of the small cylinder

Now, the costs given by *aPriori* will be unified in one *Excel* table to congregate all the information of the pieces and have a wider and clearer view of the most important costs of the whole lenses adjuster:

Component	Total Variable Costs (\$)	Piece Part Cost (\$)	Fully Burdened Cost (\$)
Main Shell	0.07	0.14	0.16
Medium Shell	0.05	0.08	0.10
Big Cylinder	0.17	0.28	0.30
Small Cylinder	0.13	0.22	0.24

Table 4: Main costs of the parts of the lenses adjuster

This estimation of the production cost of the whole lenses adjuster is \$0.80 per unit (looking at the sum of the fully burdened cost of the four parts). This may seem a high price for such a little piece, recalling the estimation from the Point 3 of \$5.50 of production cost per magnifier, but the level of detail present in the adjuster is not the same in other pieces of the product. So, with this estimation, there would be \$4.70 of production cost for the rest of the magnifier.

## 12. Generation and Evaluation of New Concepts

Now that the study is reduced only in the lenses adjuster of the magnifier of YOCTOSUN, a brainstorm of ideas must be done in order to decide how this concrete part of the magnifier is going to be improved. The updated Quality Function Deployment of point 6, the reasoning of the areas where to concentrate the design effort and the DfMA analysis will be helpful tools to perform this task.

Thus, a compilation of the conclusions made until now to do an accurate brainstorm is pertinent. From the updated QFD, it was showed that important customer requirements were the ease to use and assembly, the affordable cost, the proper magnification, the stability of the batteries and the mobility and cleaning of the lenses. After this, ideas about where to concentrate the design effort were improving the cavity for the batteries, trying to assembly some pieces so the production cost can be reduced, adding some smooth material to the head strap to better the comfortability or trying to find a way that better the mobility of the lenses.

Next, the DfMA analysis eliminated the possibility to assembly the main shell and the LED shell of the magnifier, and also to assembly the four parts of the lenses adjuster. Anyway, the part selected to be investigated was the lenses adjuster because of the possibility to join two or the parts of the adjuster and the possibility to implement a form of improving the mobility of the lenses so the users do not need to be continuously cleaning them.

Consequently, after doing this summary of all the information available, ideas about how to change the adjuster so that some of the customer requirements can be more satisfied. The more logical way to achieve good plans is to discard first what cannot be attained by changing something in the adjuster. For example, the magnification of the lenses is going to be the same no matter the change is made in this part of the product. Further, the stability of the batteries is not going to change too. This is why the design effort will be concentrated in the two main causes of taking the lenses adjuster as the studied part: the possibility of joining parts and better the assembly (and, therefore, reduce production costs) and the possibility of improving the mobility of the lenses (in this case, the functionality is what it would be innovated), but without looking at the other requirements.

Now that the focus of the analysis is clear, it is appropriate to begin to grow the different ideas that later will be compared:



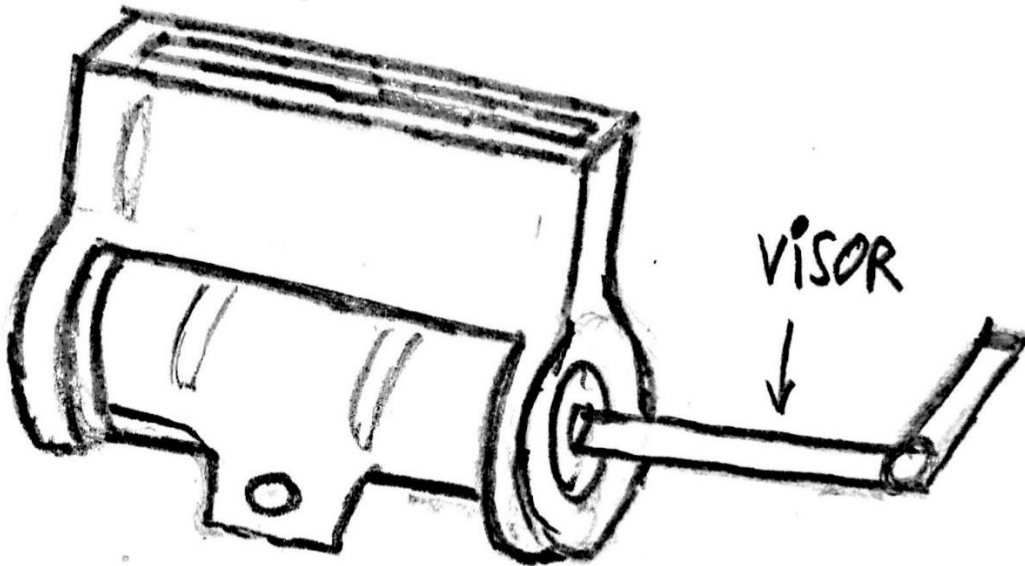
## 12.1. Development of New Concepts

### Idea 1: Adding a visor

The first idea that will be analyzed will be to add a visor to the lenses adjuster. This visor would be located on one of the lateral parts, assembled to the big cylinder. The purpose of the visor is to allow the users of the magnifier to raise and lower the lenses without touching them, so the customer requirement of “mobility and cleaning of lenses”, which is one of the most common complaints between users, would be completely supplied.

However, this idea also comes with some disadvantages. The development of adding a visor would lead to higher production costs, as a new part (the visor) is being added. Furthermore, since the cylinder is not too big, the fragility of the item would be affected too because the visor should be thin to fit in the cylinder, but it should provide enough strength to raise the lenses. Finally, the visor should not come already assembled to avoid its own break during transportation, so it should have to be assembled afterwards. This is a point against the ease to assemble the product.

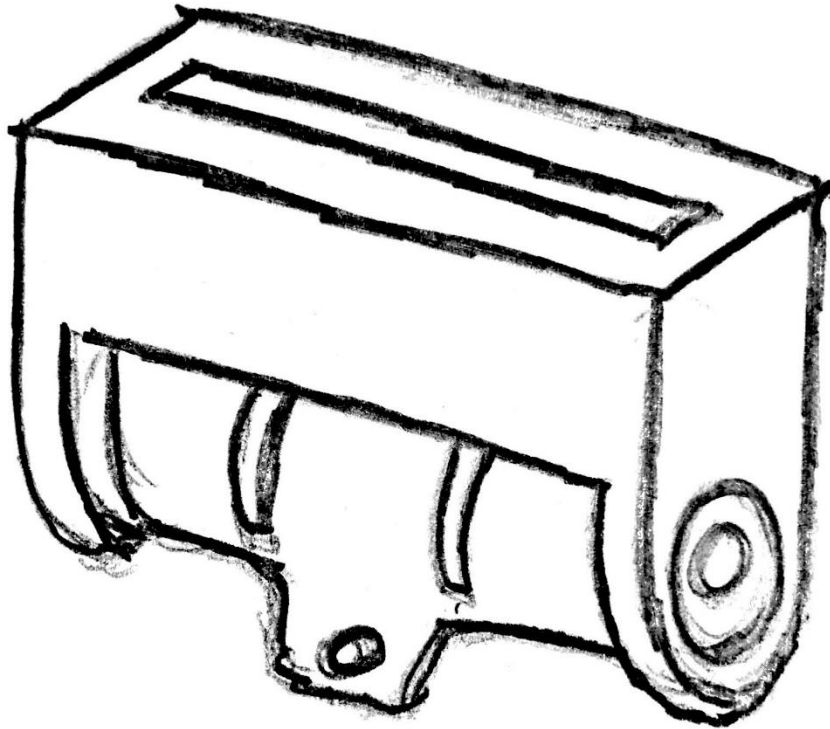
Although this concept could not reduce costs neither of manufacturing nor assembling of the product, it is related to the functionality of it. The idea would be worth enough to be carried out if the customers were able to pay an additional cost for this new function.



*Figure 28: Sketch of Idea 1: adding a visor*

## Idea 2: Changing the form of the adjuster

Another concept that would meet some customer requirements is to change the form of the adjuster itself. The change in the form that has been thought is the next:



*Figure 29: Sketch of Idea 2: changing the form of the adjuster*

With this innovation, the functionality could also be improved because the part of the adjuster that has to be held to raise and lower the lenses would be wider, so it would be more easy to the user. Moreover, the fragility of the product would be reduced and the lenses would be held with more material, so there would be less risk of them falling, which it would be appreciated by the users too.

In contrast, like it happened in the previous case, changing the form in this way would also have some disadvantages. First, the production cost would increase as there is more material in the item. Furthermore, the improvement in the functionality is not as remarkable as that in the Idea 1. Finally, there are no considerable complaints of buyers about the fastening of the lenses, which maybe makes this factor not as much important as others.

### Idea 3: Combining some elements

With this idea, there would be a reduction cost in the assembly of the product. The idea about combining the four elements of the adjuster was discarded because the medium shell did not move simultaneously with the other three parts; but the main shell and the cylinders can be assembled as they move together and are made of the same material. It is a simple concept to implement, not difficult to develop and the savings in production are clear.

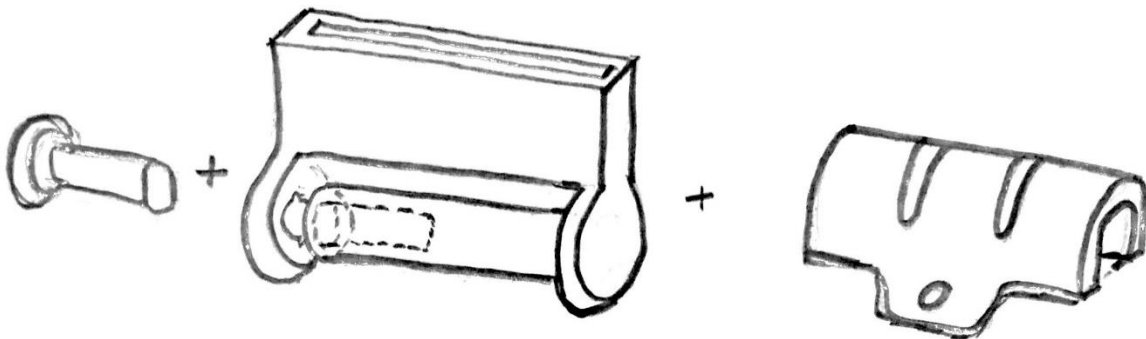
#### 12.2. Selection of most promising idea and new sub-ideas

Once that those three ideas are stated, it is opportune to select the most promising idea between them. This will let new concepts to emerge and make the final analysis to select the final design more complete.

Looking at the study done below, although it is true that the advantages may overcome the disadvantages in the two first ideas, the most promising idea seems to be combining some elements of the adjuster, as it is the only one with no clear inconveniences.

In this way, it is clear that there are three possible manners to combine the three parts: the main shell with the big cylinder, the big shell with the small cylinder, and the three parts in just one. This last is going to be directly discarded because the medium shell would rub with the big cylinder and there would be no option to disassemble the adjuster to solve this problem. So, the third idea has branched into two others: combining the main shell with the big cylinder or combining the main shell with the small cylinder.

#### Idea 3.1: Combine the main shell with the big cylinder



*Figure 30: Sketch of Idea 3.1: combine the main shell with the big cylinder*

Idea 3.2: Combine the main shell with the small cylinder

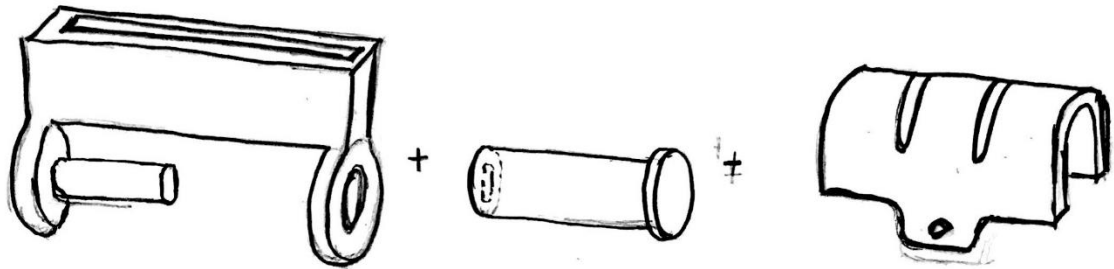


Figure 31: Sketch of Idea 3.2: combine the main shell with the small cylinder

12.3. Pugh Matrix and selection of the final idea

Now that the brainstorm and the refinement of the most promising idea is done, a comparison between the remaining purposes must be done. The Pugh Matrix is a reduced QFD, that is useful to contrast these ideas looking at what customer requirements meet each one of them:

Customer Requirement	Weigh	Visor	Change Form	Assembly 1	Assembly 2
Easy to Use	6	1	0	0	0
Low Cost	7	-1,5	-1	1,5	2
Durability	5	0	0,5	0	0
Mobility and cleaning of lenses	6	2	0,5	0	0
Fragility	5	-1	1	0	0
<b>Score</b>		<b>2,5</b>	<b>3,5</b>	<b>10,5</b>	<b>14</b>

Table 5: Pugh Matrix:

The advantages and inconveniences of the two first ideas (adding the visor and changing the form of the adjuster) were already explained. The purpose of the two last ideas is clear, reducing assembling costs so either the price of the product is reduced, or the price is the same so profits are higher. The reason why the reduction cost in the idea 3.2. (Assembly 2) is bigger than in the idea 3.1. (Assembly 1) is the next one: the difficulty of assembling the main shell and the big cylinder in just one is higher than doing it with the small cylinder because of the cavity inside the big cylinder. Building this cavity with the main shell around the big cylinder would be harder than doing it manufacturing only the big cylinder.

### 13. CAD modeling of the New Product

The Pugh Matrix selected the assembling between the main shell of the lenses adjuster and the small cylinder as the final concept to develop. After this, a first CAD modeling of this idea must be drawn so a new prototype can be printed later. Again, the program used to build this CAD modeling has been Solid Edge. Also, the dimensions of the piece will also be exposed.

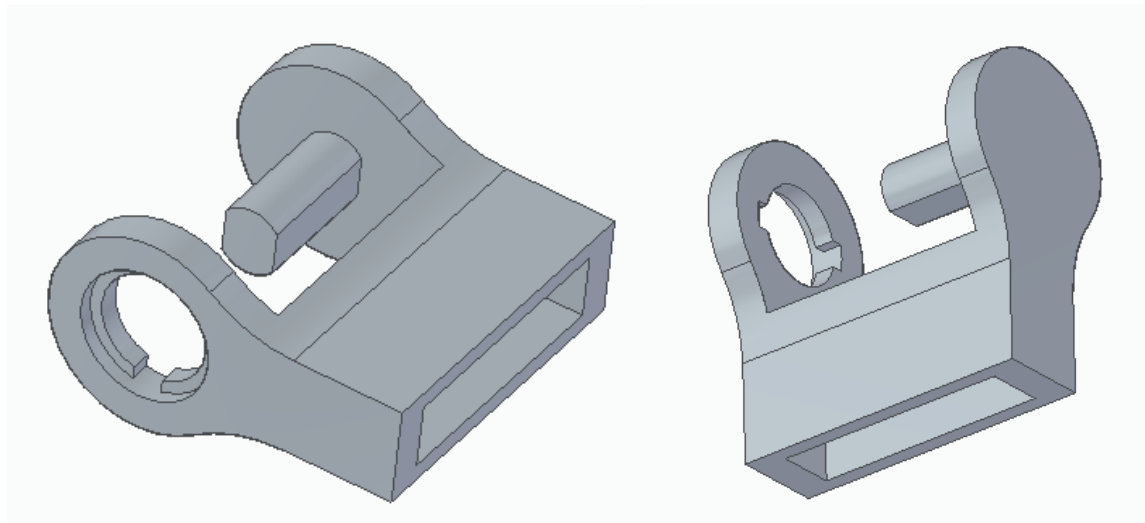


Figure 32: General view of the redesigned product

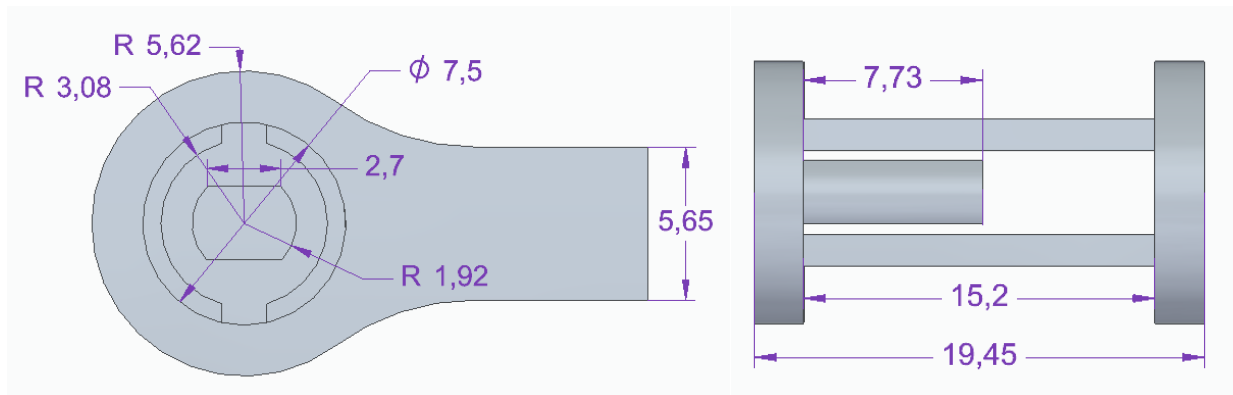


Figure 33: Dimensions of the first prototype of the redesigned part

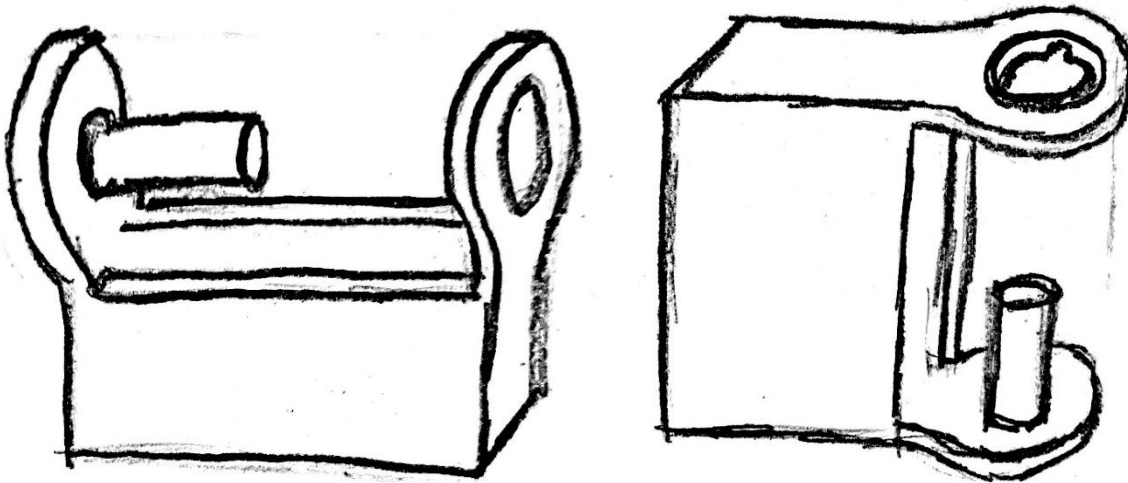
The dimensions of the redesigned part are exactly those who could correspond to the assembly of the main shell and the small cylinder. Later, it should be checked if this dimensions are accurate.

## 14. Physical prototype of the redesigned component

Once that the first prototype is done, it is ready to be physically created with 3D printing. The printers used to perform this task are *Lulzbot TAZ 6*. In the webpage of the innovation studio of the University of Illinois at Urbana-Champaign, some features and peculiarities of these printers can be found:

- It is the most reliable, easiest to use desktop 3-D printer
- Innovative self-leveling and self-cleaning
- Modular tool head design for flexible and multi-material upgrades
- Largest print volumes in its class
- Print area of 11.02 in x 11.02 in x 9.8 in and a max resolution of 50 microns

With this printer, the first prototype of the redesigned component was produced. Initially, it was not clear how to place the piece to not get a lot of support material (being a little component, it is a hard task to remove it), but also get a good accuracy in the hole for the big cylinder. The best option to get the least possible remove material was placing the piece as in the first sketch of Figure 33, but the most convenient position to ensure that the hole is almost perfectly round was that showed in the second one:



*Figure 34: Sketch of the two possible ways to place the piece to 3D print*

Trying to make a balance between these two options, more importance was given to the accurate form of the big cylinder hole. Because of this, the second option was selected. However, after printing it, the piece got broken in the trial of removing all the support material. Therefore, it was printed again, but now with a 10% of it.

In this case, the remove material was taken out without bigger inconvenience. Nevertheless, when the big cylinder was tried to insert into the new piece, it did not fit in the hole made for this purpose, so the redesigned part was printed again at a scale of 105%.

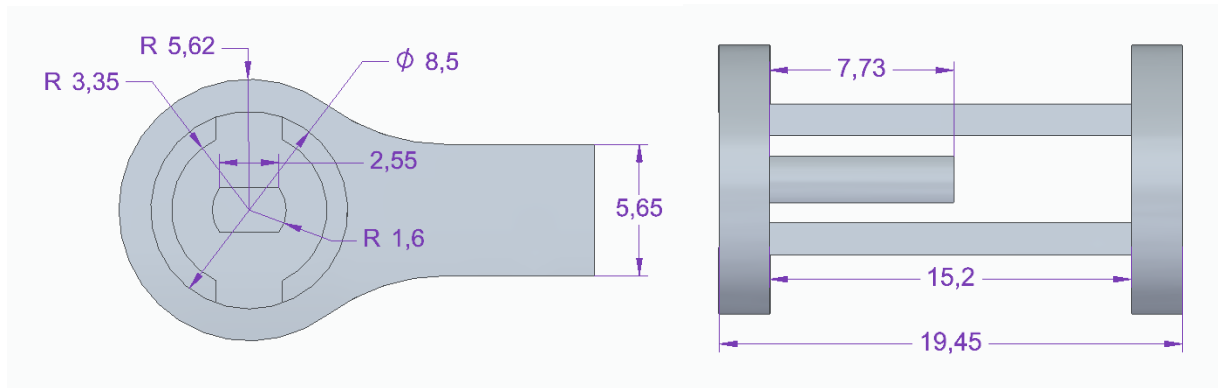
In this try, the big cylinder did fit into its hole with this new version, but it was the small cylinder what did not into the hole inside the big cylinder as it had increased its dimensions 105% too. This small cylinder was filed to prove the functionality of the redesigned product, and this is the result:



*Figure 35: Filed first prototype of the redesigned product*

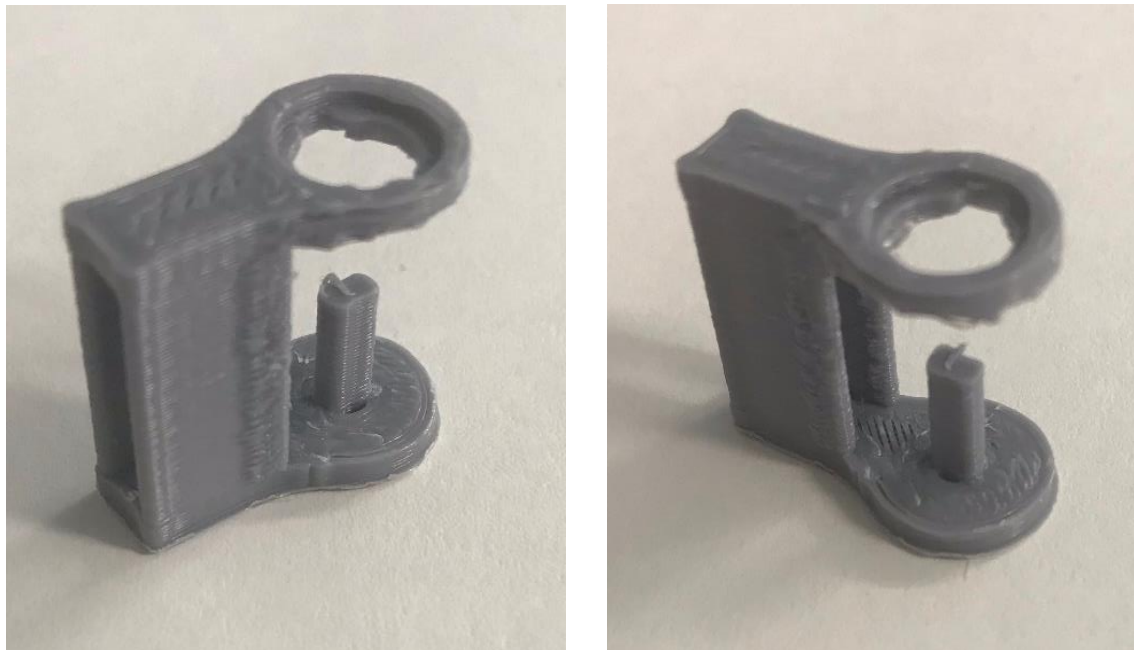
Although this is a rude way of studying the functionality, it serves as a first view of what it has to be redesigned and what do not. As it seems that the tolerances of the new part were too adjusted, the hole size was slightly increased, and the small cylinder slightly decreased. The dimensions of this new part are as follows:





*Figure 36: Dimensions of the second prototype of the redesigned products*

Furthermore, this time, 3 different versions of this resized design were printed (100% of the new dimensions, 102% and 104%), to minimize the probability of printing again. The placing of the product and the percentage of support material is the same as in the previous printings. Tries were made with these parts, and the big cylinder fit well in every of them, but it adjusted better in the 100% of scale version.



*Figure 37: Improved redesigned product*





*Figure 38: Assembling of the big cylinder with the improved redesigned product*

As the big cylinder fits perfectly in the redesigned model, this has been chosen as the final design. To ensure its functionality, a proof of functionality with the lenses was also required:



*Figure 39: Assembling of the glasses with the improved redesigned product*

## 15. Design of experiment method

Although the functionality of the new product has just been proved to be the same (the new part of the lenses adjuster assembles perfectly with the big cylinder and with the lenses), it is pertinent to design an experiment method with which some variables of the magnifier can be measured and so the old and the modern versions can be compared.

Therefore, the first step required to design this experiment is choosing the variables that are going to be involved in it. Since what has been improved in the product is the reduction of the number of pieces, one direct consequence of this should be a decrease in the assembly time, so this is the output variable that is going to be measured and tested.

Furthermore, the input or design variables will be:

- $X_1$ : the number of components (which is opportune regarding the main purpose of the redesigned part)
- $X_2$ : the size of the magnifier
- $X_3$ : the main material of the magnifier (in other words, the material of the main shell, the LED shell and the ear temples).

Now, two values will be chosen for the input variables to later see how they affect (both separately and interacted with the other ones) to the output variable. The “low” value will be that one who makes the assembly time lower, and the “high” value will be that one that makes the assembly time high.

Variable	Low (-1)	High (+1)
<b><math>X_1</math>: number of components</b>	23	24
<b><math>X_2</math>: size of the magnifier (mm)</b>	300	250
<b><math>X_3</math>: material of the magnifier</b>	ABS	PP

*Table 6: Variable low and high levels*

The “low” value and the “high” value for the number of components is the real change that the magnifier is experimenting while assembling the main shell of the lenses adjuster and the small cylinder in just one part. Moreover, it has been assumed that, the bigger the magnifier, the easier

to assemble it (so the less time that it takes), and also that if it is made of ABS plastic it will take shorter than if it is made of PP (polypropylene).

Besides, in order to have a good accuracy in the randomized measures of the output variable, the theoretical assembly time will be calculated both for the previous version of the magnifier and for the modified one. This task will be performed with an estimation learnt in the Lab 6, in the course Design for Manufacturability (ME270, University of Illinois at Urbana-Champaign):

Operation Number	Number of operations	Part Description	Part Required	Alpha (deg)	Beta (deg)	Size (mm)	Thickness (mm)	Handling and Alingment		Insert and Secure		Total Time (sec)
								Description	Time (sec)	Description	Time (sec)	
1	1	Main shell and electrical components	Yes	360	360	145	40	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s Align to small hole: 0.3s	0,8	3,3
2	1	Rubber front pad	Yes	360	360	90	10	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s Snap: 0.3s	0,8	3,3
3	1	LED shell	Yes	360	360	65	20	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s	0,5	3
4	2	Ear temples	Yes	360	360	130	5	Part fetch time: 0.5s Symmetry: 2s Aspect ratio: 0.1s	2,6	General placement: 0.5s Snap:0.3s	0,8	6,8
5	2	Hoops	Yes	180	0	10	2	Part fetch time: 0.5s Symmetry: 0.5s Part size:0.5s	1,5	General placement: 0.5s	0,5	4
6	2	Cylindrical side plugs	Yes	360	0	10	10	Part fetch time: 0.5s Symmetry: 1s	1,5	General placement: 0.5s	0,5	4
7	1	Inside top	Yes	360	360	20	3	Part fetch time: 0.5s Symmetry: 1,5s	2	General placement: 0.5s	0,5	2,5
8	1	Lenses adjuster main shell	No	360	180	20	10	Part fetch time: 0.5s Symmetry: 1.5s	2	General placement: 0.5s Insertion difficulty: 0.4s	0,9	2,9
9	1	Lenses adjuster big cylinder	Yes	360	180	15	7	Part fetch time: 0.5s Symmetry: 1.5s Part size: 0.5s	2,5	General placement: 0.5s Insertion difficulty: 0.4s	0,9	3,4
10	1	Lenses adjuster medium shell	Yes	0	180	19	10	Part fetch time: 0.5s Symmetry: 0.5s Part size:0.5s	1,5	General placement: 0.5s Snap: 0.3s	0,8	2,3
11	1	Lenses adjuster small cylinder	No	360	180	10	7	Part fetch time: 0.5s Symmetry: 1.5s Part size:0.5s Handling difficulty: 0.4s	2,4	General placement: 0.5s Insertion difficulty: 0.4s	0,9	3,3
12	2	Small narrow screws	Yes	360	0	6	2	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion:1s Final screw tightening: 2s	3,8	11,6
13	3	Large narrow screws	Yes	360	0	13	2	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion:1s Final screw tightening: 2s	3,8	17,4
14	2	Small wide screws	Yes	360	0	6	3	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion:1s Final screw tightening: 2s	3,8	11,6
15	2	Large wide screws	Yes	360	0	12	3	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion:1s Final screw tightening: 2s	3,8	11,6
16	1	Nose adjuster	Yes	360	360	35	10	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s	0,5	3
<b>Total AssemblyTime</b>											<b>94</b>	

Figure 40: Calculation of assembly time for the original magnifier

And for the redesigned product:

Operation Number	Number of operations	Part Description	Part Required	Alpha (deg)	Beta (deg)	Size (mm)	Thickness (mm)	Handling and Alingment		Insert and Secure		Total Time (sec)
								Description	Time (sec)	Description	Time (sec)	
1	1	Main shell and electrical components	Yes	360	360	145	40	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s Align to small hole: 0.3s	0,8	3,3
2	1	Rubber front pad	Yes	360	360	90	10	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s Snap: 0.3s	0,8	3,3
3	1	LED shell	Yes	360	360	65	20	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s	0,5	3
4	2	Ear temples	Yes	360	360	130	5	Part fetch time: 0.5s Symmetry: 2s Aspect ratio: 0.1s	2,6	General placement: 0.5s Snap: 0.3s	0,8	6,8
5	2	Hoops	Yes	180	0	10	2	Part fetch time: 0.5s Symmetry: 0.5s Part size: 0.5s	1,5	General placement: 0.5s	0,5	4
6	2	Cylindrical side plugs	Yes	360	0	10	10	Part fetch time: 0.5s Symmetry: 1s	1,5	General placement: 0.5s	0,5	4
7	1	Inside top	Yes	360	360	20	3	Part fetch time: 0.5s Symmetry: 1,5s	2	General placement: 0.5s	0,5	2,5
8	1	NEW PRODUCT (lenses adjuster main shell + lenses	Yes	360	360	20	10	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s Insertion difficulty: 0.4s	0,9	3,4
9	1	Lenses adjuster big cylinder	Yes	360	180	15	7	Part fetch time: 0.5s Symmetry: 1.5s Part size: 0.5s	2,5	General placement: 0.5s	0,5	3
10	1	Lenses adjuster medium shell	Yes	0	180	19	10	Part fetch time: 0.5s Symmetry: 0.5s Part size: 0.5s	1,5	General placement: 0.5s Snap: 0.3s	0,8	2,3
11	2	Small narrow screws	Yes	360	0	6	2	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion: 1s Final screw tightening: 2s	3,8	11,6
12	3	Large narrow screws	Yes	360	0	13	2	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion: 1s Final screw tightening: 2s	3,8	17,4
13	2	Small wide screws	Yes	360	0	6	3	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion: 1s Final screw tightening: 2s	3,8	11,6
14	2	Large wide screws	Yes	360	0	12	3	Part fetch time: 0.5s Symmetry: 1s Part size: 0.5s	2	General placement: 0.5s Align to medium hole: 0.3s Turning insertion: 1s Final screw tightening: 2s	3,8	11,6
15	1	Nose adjuster	Yes	360	360	35	10	Part fetch time: 0.5s Symmetry: 2s	2,5	General placement: 0.5s	0,5	3
<b>Total AssemblyTime</b>											<b>90,8</b>	

Figure 41: Calculation of the assembly time for the magnifier with the redesigned part

Regarding the developing of the experiment, a prototype testing now will be planned. First, as there are three variables that will be examined and each of them has two levels (one high, one low), there will be  $2^3 = 8$  unique test conditions. This means that there will be 8 different combinations of the design variables, and it was decided that for each condition, there will be three trials (three measures of the assembly time). With this information, the design matrix can be already filled with all the random measures of the output variable for each condition:

<b>Combination</b>	<b>0</b> <b>x1</b>	<b>0</b> <b>x2</b>	<b>0</b> <b>x3</b>	<b>Trial 1</b> <b>defects</b>	<b>Trial 2</b> <b>defects</b>	<b>Trial 3</b> <b>defects</b>	<b>Avg.</b> <b>Defects</b>
1	-1	-1	-1	89,3	89,5	89,2	89,3
2	1	-1	-1	92,8	93,0	92,6	92,8
3	-1	1	-1	90,8	90,7	91,1	90,9
4	1	1	-1	94,2	94,4	94,0	94,2
5	-1	-1	1	89,6	89,3	89,5	89,5
6	1	-1	1	93,1	93,1	92,7	93,0
7	-1	1	1	91,1	90,9	91,0	91,0
8	1	1	1	94,5	94,3	93,9	94,2

*Table 7: Design matrix*

The values that appear in this table are randomized measures or number of defects (three replicates of each condition) of the output variable based on the theoretical assembly times calculated previously. Moreover, the average number of defects for each combination was calculated (using its Excel function) because it is going to be needed later.

In case this experiment was desired to carry on this experiment in real life, a person timing the assembly time with a chronometer would be needed. Since it would be hard to get the accurate first decimal for this variable, more measures would be required to have a proper average for each condition.

Also, if more precision would be wanted, the solution could be having more people timing the process. This would allow to obtain more measures of the different cases, so the deviations due to human errors would be decreased and the average would get closer to a more logical number, and the results of the experiment would be more meticulous and rigorous. Besides, the more precise and modern the chronometers, the more accurate the measures of assembly time.

Moreover, those outlier measures due to unexpected factors (for example, a machine that stops working or a piece that gets broken), should be eliminated so that the average for every type of combination of design variables could be a reasonable number.

Turning back to the statistics from the table above, it is pertinent to point out a couple of aspects. On the one hand, if one concrete input variable is wanted to be analyzed, there are four different

couple of combinations that share the level of the other two input variables, and only change in the one that is being studied. For example, evaluating the effects of the material of the magnifier, combination 5 would be the couple of combination 1, as the two first design variable are in their “low” level, but the material differs from one combination to another.

Therefore, looking at the differences in the average number of the four pairs for each input variable, the impact on the output variable of each variable on its own, as well as the impact of the mix of two or the three variables can be considered and interpreted. The interaction variables will be called as follows:

- $X_{12}$ : interaction of the number of components combined with the size of the product.
- $X_{13}$ : interaction of the number of components combined with the material of the product.
- $X_{23}$ : interaction of the material combined with the size of the product.
- $X_{123}$ : combined interaction of the three input variables.

After this, the next step is calculating the effect value (E) that each X has on the assembly time. To perform this, the Calculation matrix is required, which encompasses the effects of each X and the variance of every combination of the input variables. For example, to calculate the column of  $X_1X_2$ , the columns of  $X_1$  with  $X_2$  are multiplied:

Test	$X_1$	$X_2$	$X_3$	$X_1X_2$	$X_1X_3$	$X_2X_3$	$X_1X_2X_3$	Average Defects
1	-1	-1	-1	+1	+1	+1	-1	89,3
2	+1	-1	-1	-1	-1	+1	+1	92,8
3	-1	+1	-1	-1	+1	-1	+1	90,9
4	+1	+1	-1	+1	-1	-1	-1	94,2
5	-1	-1	+1	+1	-1	-1	+1	89,5
6	+1	-1	+1	-1	+1	-1	-1	93,0
7	-1	+1	+1	-1	-1	+1	-1	91,0
8	+1	+1	+1	+1	+1	+1	+1	94,2

Table 8: Calculation Matrix

Once this matrix is refilled, every effect value can already be calculated. For example, to calculate  $E_1$ , each sign in column the first column must be multiplied by its corresponding average number of defects, and then sum all these values. Finally, this sum must be divided by the by half the number of test (in this case, divided by 4). Since every effect value is calculated the same way (with its corresponding column), only the equation for  $E_1$  will be showed (every effect value will be exposed later):

$$E_1 = \frac{1}{4}[-89,3 + 92,8 - 90,9 + 94,2 - 89,5 + 93,0 - 91,0 + 94,2] = 3,383$$

*Equation 1: Calculation of the effect value for the number of components*

As it was stated before, each effect measures the impact of its variable (or combination of variables) in the output variable. Because of this, it must be chosen which effects are statistically significant and which ones do not really make a difference on the assembly time. This will be operated by using the graphical significance method:

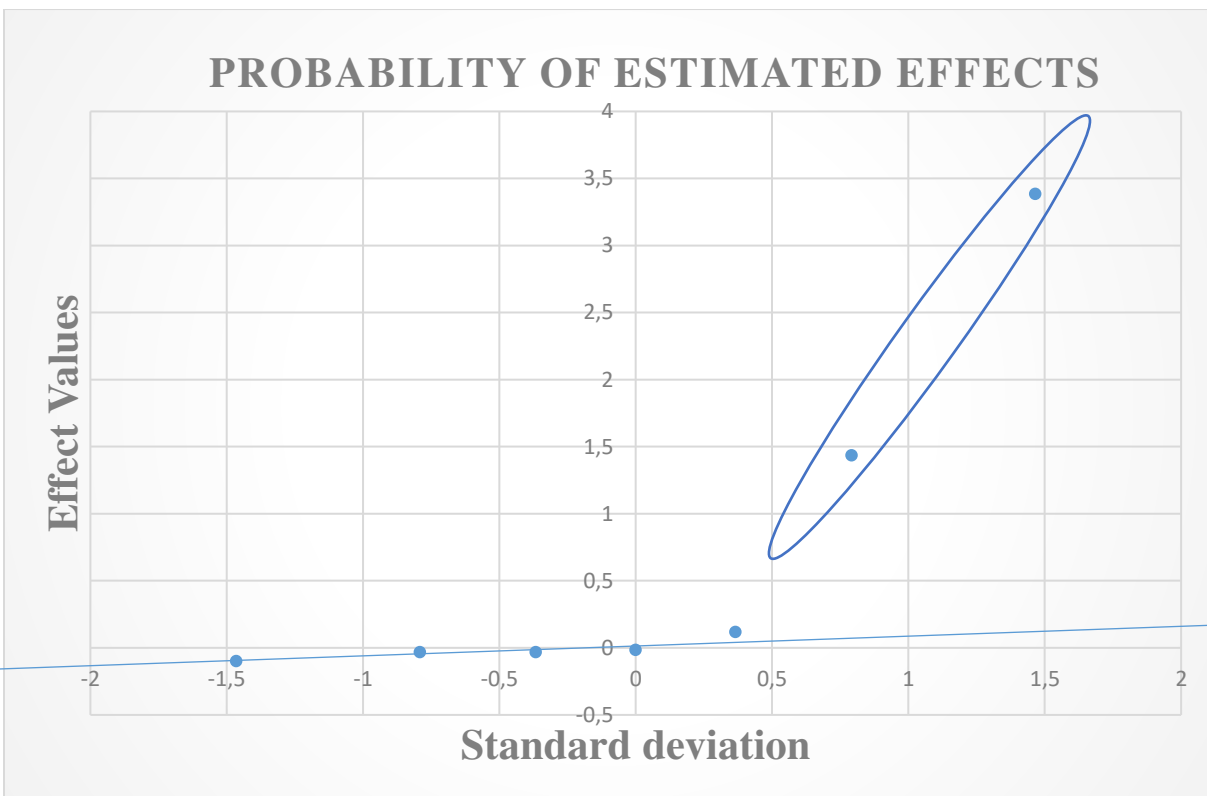
Rank	1	2	3	4	5	6	7
Effect value	3.383	1.433	0.117	-0.017	-0.033	-0.033	-0.1
Probability (%)	92.86	78.57	64.29	50	35.71	21.43	7.14
Standard Dev.	1.47	0.79	0.37	0.00	-0.37	-0.79	-1.47
Effect	$E_1$	$E_2$	$E_3$	$E_{13}$	$E_{23}$	$E_{123}$	$E_{12}$

*Table 9: Ranked effects and their corresponding probabilities*

Thus, this method is based on characterizing each effect value with a portion of the distribution (being 100% the whole distribution of the effect values). The smallest effect value will be corresponded to the first portion (1/7 of the distribution, 14.3%), in this case,  $E_{12}$ , and it will be assigned the midpoint of its interval. The second smallest effect value ( $E_{123}$ ) is assigned to the second interval, and so on. Also, standard deviations for each interval are calculated using the

“NORM.INV” function in Excel, so we can converse our effect values to an ideal normal distribution and then plot it to analyze the impact of each effect.

Once the plot is done, a straight line must be drawn matching the point that has a standard deviation of 0 (in this experiment,  $E_{13}$ ) and the point immediately adjacent that gives the most shallow (smallest in magnitude) slope. All the effect values that are over this line in the right hand and below the line in the left hand will be considered significant (the further to the line, the more significant effect):



*Graph 1: Normal probability plot of the estimated effects*

Analyzing the results of this graph, it seems that the results of the experiment meet with the expectations. There are two significant points, which correspond to  $E_1$  and  $E_3$ . The point that corresponds to  $E_3$  is also above the line but is as near to it that it cannot be considered significant enough to be taken into account.

Therefore, the results of the experiment show that the number of components in the magnifier and the size of the magnifier has an appreciable impact on the assembly time, and also that no



combination of input variable has effect on the output variable. Regarding the assembly time, this is a reasonable conclusion as the theoretical calculations showed that the assembly time was shorter with the redesigned component (23 parts, 90.8 seconds) than with the two original pieces (24 parts, 94 seconds). Furthermore, regarding the size of the magnifier, it makes sense that assembling bigger pieces takes less time. Nevertheless, as the item must adapt to the head, the dimensions of it should not be appreciably changed. Finally, the results for the third variable are logical too, as the material of the magnifier (as long as it must be plastic to produce it at an affordable price) should not lead to a substantial change in the assembly time.

## 16. Comparison of the original and the redesigned product

All this process and redesigning would have no sense if a final comparison between the original and the new product was not carried out. Because of this, a final contrast between the two products will be developed.

Recalling the theoretical assembly times calculated for both products, there is a difference between them of 3.2 seconds of assembly. The reason for this change is obvious: in the redesigned lenses adjuster, there is no small cylinder to assemble, so looking at its assembly time in Figure 38 (3.3 seconds), a very accurate evaluation of the reduction in this variable can be made. The difference is not exact the same ( $94 - 90.2 = 3.8$  seconds) because now that the two parts are assembled, it is considered that the main shell is no more difficult to insert.

In terms of the implications that this adjustment in the assembly time will bring, the main one is going to be the impact in the production costs to YOCTOSUN. Turning back to the estimated magnifiers sold per year (25,000 units) and knowing that an original magnifier takes 94 seconds to be assembled, the total assembling time per year amounts to  $25,000 \times 94 = 2,350,000$  seconds. With this number, the new total units produced per year can be calculated:

$$\frac{\text{Total assembling time in a year}}{\text{Assembling time for the redesigned product}} = \frac{2,350,000 \text{ seconds}}{90,8 \text{ seconds}} = 25,881 \text{ units}$$

*Equation 2: New number of magnifiers produced per year*

Therefore, as almost 900 magnifiers more per year can be produced, YOCTOSUN has two options with this improvement. On the one hand, they can lower the price in order to obtain more competitive advantage against its competitors. On the other hand, they would be able to maintain the same price for the product and earn more profits.

In this way, analyzing the position that YOCTOSUN magnifiers are in the market and looking at the Quality Function Deployment and the differences between the main magnifying sellers, it is logical to think that the first option is more interesting. This is because the customers that buy this item to YOCTOSUN are not looking to a very high-quality, but they are looking for a product that meets the main requirements for the most affordable price. If YOCTOSUN reduces the price of

the magnifier, probably they could capture the customers of Housweety LED and SE Illuminated, as they could offer better benefits at the same price.

Moreover, the program *aPriori* can give some help again to analyze the production costs. These are the results that the program provides with the redesigned product.



	Current (USD)
<b>Variable Costs</b>	
Material Cost	<0.01
Labor	0.05
Direct Overhead	0.02
Amortized Batch Setup	0.02
Logistics	0.00
▲Other Direct Costs	<0.01
<b>Total Variable Costs</b>	0.08
<b>Period Costs</b>	
Indirect Overhead	0.05
SG&A	0.01
Margin	0.00
<b>Piece Part Cost</b>	0.14
<b>Fixed Costs</b>	
▲Total Amortized Investments	0.03
<b>Fully Burdened Cost</b>	0.17
<b>Capital Costs</b>	
▲Total Capital Investments	13,217.86

Figure 42: Main costs of the redesigned part

A similar cost approximation can be done with these results. In the next table, we can see the main costs for the original main shell of the lenses adjuster, the original small cylinder and the redesigned product that combines those two:

Component	Total Variable Costs	Piece Part Cost	Fully Burdened Cost
Main Shell	0.07	0.14	0.16
Small Cylinder	0.13	0.22	0.24
Sum of the two parts	0.20	0.36	<b>0.40</b>
Redesigned part	0.08	0.14	<b>0.17</b>

Table 10: Comparison of the cost between the original parts and the redesigned part

Thus, a clear cost reduction has taken place: producing the two components separately costed \$0.40, while producing one unit of the redesigned part costs \$0,17 (57.5% of cost reduction in the production cost of this particular part, always following the *aPriori* estimation). This means that \$0.23 would be saved for every magnifier that is being produced. Therefore, as 25,000 units are

sold per year, this would be the amount saved (assuming that they are not lowering the price) by YOCTOSUN with this change:

$$\text{Amount saved} = 25,000 \text{ units} \times \$0.23 = \$5,570$$

*Equation 3: Amount saved by YOCTOSUN per year with the redesigned component*

Finally, the quality and functionality of the original and the new product must also be analyzed. The merit of this process is getting to a reduction in the assembly time (and, therefore, to a cost reduction) without harming quality and functionality at all. Any part of this study would have had sense if the magnifier were less functional with the new version. This is why the new model was 3D printed and assembled with the rest of the magnifier and the glasses again. In such a technological market as it is where YOCTOSUN develops its activity, one cannot afford a damage in quality nor in functionality.

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