COMILLAS
UNIVERSIDAD PONTIFICIA

ICAI

GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

RE-DESIGN FOR MANUFACTURABILITY: DIRT DEVIL SD2000

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Madrid

Junio de 2019

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Fdo.: Gabriel Pérez Plata Date: 8/05/2019

I authorize the submission of this project

PROJECT SUPERVISOR

17 June 2019

Fdo.: Leon Liebenberg Date:

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REDISEÑO PARA LA MANUFACTURACIÓN: DIRT DEVIL SD2000

Autor: Pérez Plata, Gabriel.

Director: Liebenberg, Leon.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

RESUMEN DEL PROYECTO

El objetivo principal de este proyecto es realizar un análisis completo y una posterior modificación que afecte a la fabricación y funcionabilidad de un producto existente en el mercado con el fin de disminuir los costos de producción y, en menor medida, mejorar la funcionabilidad del producto.

El producto sometido a estudio es una aspiradora de la marca Dirt Devil, modelo SD2000. Esta aspiradora se encuentra dentro del sector de las aspiradoras escoba con opción de convertirse en una aspiradora de mano, además, debido a su precio también se puede agrupar en el sector de las aspiradoras low-cost.

Para poder llevar a cabo una modificación y mejora en el producto es necesario realizar una serie de análisis que nos permitan conocer las especificaciones, necesidades, aspectos a mejorar y costes de fabricación. En primer lugar, se realiza un análisis físico del producto llevando a cabo el desmontaje y la posterior lista de materiales y piezas que nos permita conocer la composición y funcionamiento de nuestra aspiradora. En segundo lugar, es necesario conocer las especificaciones técnicas, el estado del mercado actual de las aspiradoras, las necesidades de los clientes y la posición de nuestro producto respecto a los competidores para poder así encontrar los aspectos a mejorar y poder diseñar la hoja de ruta que deben seguir las modificaciones para conseguir una mejora de la posición del producto en el mercado. Tras finalizar dichos análisis se llega a la conclusión que es necesaria una mejora de la ergonomía y de la comodidad por lo que se opta la incorporación de un mango extensible que permita diferentes posiciones, consiguiendo una mayor adaptabilidad para el usuario, reduciendo a su vez el tamaño de almacenaje, otro de los principales requerimientos de los usuarios.

En cuanto a la producción, reducir el coste de fabricación del producto se traduce en mayores ganancias para la empresa o en una bajada del precio del producto, lo que al pertenecer al sector low-cost se convertiría en un factor

diferencial con el resto de los competidores. Para poder llevar a cabo dicha mejora es necesario conocer cómo se fabrica y ensambla actualmente el producto y cuál es el precio de manufacturación de cada unidad con el fin de encontrar ares de mejora y poder comparar, en última instancia, si el producto modificado consigue disminuir dicho coste de fabricación. Debido a que estos datos son confidenciales y la empresa no hace públicos los métodos de producción ni los materiales que utilizan es necesario hacer diversos análisis que nos permitan conocer más datos sobre cómo se fabrica y poder así realizar una estimación de los costes. La aspiradora bajo estudio está fabricada casi en su totalidad de plástico, concretamente ABS, exceptuando contadas partes como el mango, fabricado en acero inoxidable. Las piezas de plástico son fabricadas con la técnica de moldeo por inyección, dicha técnica consiste en inyectar plástico dentro de un molde donde se solidifica, obteniendo así la pieza con la forma deseada. Esta técnica es una de la más utilizada para fabricar piezas de plástico debido a su bajo coste y su buen rendimiento por lo que el margen de mejora en estas piezas es muy pequeño. Sin embargo, debido a que el mango está fabricado de acero inoxidable, se lleva a cabo un análisis especifico de esta pieza para poder conocer su precio de fabricación y posibles alternativas a dicho material. Para poder conocer el precio de fabricación se utiliza el software informático Apriori, el cual, utilizando un modelo en 3D, previamente diseñado con los softwares de diseño Solid Edge y Creo Parametrics, permite estimar en base al material y método de fabricación utilizado el coste aproximado de la pieza. Este análisis nos arroja que el precio de producción de la pieza es significativamente alto, por lo que se exploran opciones que nos permitan reducir dicho coste y añadir además las nuevas funcionabilidades tratadas anteriormente. Otra de las alternativas que hay para reducir costes de producción es la simplificación del ensamblaje, si se consigue disminuir el número de elementos externos como tornillos o reducir el tiempo necesario de ensamblaje se reducirá notoriamente el precio final del producto. Sin embargo, el diseño actual del producto es óptimo en este aspecto ya que utiliza un número reducido de tornillos y la mayoría de las piezas se unen a través de pestañas y otras técnicas sin necesidad de elementos externos ni de herramientas específicas.

Tras llevar a cabo las nuevas modificaciones que mejoran la funcionalidad del mango, realizadas con el software de diseño 3D Creo Parametrics, se realiza un prototipo físico gracias a una impresora 3D Lulzbot TAZ 6 y se prueban las nuevas funcionabilidades. Este prototipo sirve para descartar el plástico como alternativa al acero inoxidable ya que no es suficientemente resistente para la tarea para la cual está diseñado. Estas modificaciones es la sustitución del mango rígido por un mango extensible que consta de dos tubos concéntricos de forma triangular, misma forma que la de la pieza original, que se insertan uno dentro del otro. El tubo interior posee una cavidad en la que se inserta un botón junto con un muelle que permite fijar la posición del tubo interior respecto al exterior gracias a los agujeros que este último posee.

Esta modificación permite fijar el mango en tres posiciones diferentes más otra posición de plegado, lo que, además de un aumento de la ergonomía del producto y de la comodidad del consumidor, permite reducir en 70mm la longitud mínima del producto, disminuyendo el tamaño de almacenaje y de transporte, lo que conlleva una disminución en los costes de envió y de transporte.

Para conseguir una disminución en los costes de producción se ha optado por cambiar el material del mango, para lo que se hecho un estudio de diferentes materiales que tengan características mecánicas suficientes para aguantar la tarea para la cual está diseñada y que tengan un menor coste que el acero. Debido a que el uso del plástico, el cual reduciría drásticamente el precio de la pieza al ser el material usado en el resto del producto, se ha descartado por ser tener propiedades mecánicas insuficientes, se ha optado por la utilización de aluminio, un material comúnmente usado en pequeños electrodomésticos y con unas características mecánicas suficientes. Tras utilizar el software Apriori para estimar el precio de la nueva pieza, con las nuevas modificaciones que afectan a la funcionabilidad, el cambio de material permite una reducción de 0.82$ pese a que la nueva pieza es más compleja, necesita más material y se compone de más partes. Gracias a una estimación aproximada de las ventas de este producto a lo largo del año, se estima que esta mejora permitiría a la empresa aumentar las ganancias en unos 123.000$.

<table>
<tr><th></th><th colspan="2">Precio por pieza</th><th>Precio total</th></tr>
<tr><td>Pieza original</td><td colspan="2">1.52$</td><td>1.52$</td></tr>
<tr><td rowspan="4">Pieza modificada</td><td>Pieza interior</td><td>0.23$</td><td rowspan="4">0.7$</td></tr>
<tr><td>Pieza exterior</td><td>0.26$</td></tr>
<tr><td>Botón</td><td>0.16$</td></tr>
<tr><td>Muelle</td><td>0.05$</td></tr>
<tr><td></td><td></td><td>Ahorro</td><td>0.82$</td></tr>
</table>

También se ha realizado un diseño de experimento DOE ficticio que permita efectuar, si se lleva a cabo un experimento real con clientes, un estudio que permita conocer si los cambios implementados satisfacen al cliente y en qué medida cada uno de los factores como el material del mango o su funcionabilidad afectan a dicha satisfacción del cliente.

RE-DESIGN FOR MANUFACTURABILITY: DIRT DEVIL SD2000: DIRT DEVIL SD2000

The main objective of this project is to carry out a complete analysis and a subsequent modification that affects the manufacture and functionality of an existing product in the market in order to reduce production costs and, to a lesser extent, improve the functionality of the product.

The product under study is a vacuum cleaner of the Dirt Devil brand, model SD2000. This vacuum cleaner is inside the sector of stick vacuum cleaners with option to become a hand vacuum cleaner, also, due to its price can also be grouped in the sector of low-cost vacuum cleaners.

In order to carry out a modification and improvement in the product, it is necessary to accomplish a series of analyzes that allow us to know the specifications, needs, aspects to be improved and manufacturing costs. In the first place, a physical analysis of the product is realized, carrying out the dismantling and the subsequent list of materials and pieces that allow us to know the composition and operation of our vacuum cleaner. Secondly, it is necessary to know the technical specifications, the state of the current market of the vacuum cleaners, the needs of the customers and the position of our product with respect to the competitors in order to find the aspects to improve and design the roadmap that the modifications must follow to obtain an improvement of the position of the product in the market. After completing these analyzes, it is concluded that an improvement in ergonomics and comfort is necessary, that is why the addition of an extendable handle that allows different positions is choosen, achieving a greater adaptability for the user, reducing in turn the storage size, another of the main requirements of users.

In terms of production, reducing the cost of manufacturing the product is translated into greater profits for the company or a fall in the price of the product, which, since it belongs to the low-cost sector, would become a differential factor with the rest of the competitors. To be able to accomplish this improvement it is necessary to know how the product is currently manufactured and assembled and what is the manufacturing price of each unit in order to find areas of improvement and be able to compare, ultimately, if the modified product manages to reduce said manufacturing cost. Because these data are confidential and the company does not publish the production methods or the materials they use, it is necessary to carry out various analyzes that allow us to know more about how it is manufactured and thus be able to estimate the costs. The vacuum cleaner under study is made almost entirely of plastic, specifically ABS, except for a few parts such as the handle, made of stainless steel. The plastic parts are manufactured with the technique of injection molding, said technique consist in injecting plastic into a mold where it solidifies, thus obtaining the piece with the desired shape. This technique is one of the most used to manufacture plastic parts due to its low cost and good performance, so the margin for improvement in these parts is very small. However, because the handle is made of stainless steel, a specific analysis of this piece is performed in order to know its manufacturing price and possible alternatives to said material. To know the manufacturing price, the Apriori computer software is used, which, using a 3D model previously designed with the design softwares Solid Edge and Creo Parametrics, allows estimating the approximate cost, based on the material and manufacturing method used, of the piece. This analysis shows that the production price of the piece is significantly high, so we explore options that allow to reduce this cost and also add the new functions treated previously. Another of the alternatives that there is is to reduce production costs is to simplify the assembly, if it is possible to reduce the number of external elements such as screws or reduce the necessary assembly time, the final price of the product will be markedly lower. However, the current design of the product is optimal in this aspect since it uses a reduced number of screws and most of the pieces are joined through tabs and other techniques without the need for external elements or specific tools.

After perform the new modifications that improve the functionality of the handle, made with the 3D design software Creo Parametrics, a physical prototype is made thanks to a 3D printer Lulzbot TAZ 6 and the new functionalities are tested. This prototype serves to discard the plastic as an alternative to stainless steel because it is not strong enough for the task for which it is designed. These modifications is the replacement of the rigid handle by an extendable handle consisting of two concentric tubes of triangular shape, same shape as that of the original part, which are inserted one inside the other. The inner tube has a cavity in which a button is inserted together with a spring that allows to fix the position of the inner tube with respect to the outside thanks to the holes that the latter has.

This modification allows to fix the handle in three different positions plus another folding position, which, in addition to an increase in the ergonomics of the product and the comfort of the consumer, allows to reduce in 70mm the minimum length of the product, decreasing the storage and transport size, which leads to a reduction in shipping and transport costs.

To achieve a reduction in production costs, it has been decided to change the material of the handle, for which a study was made of different materials that have sufficient mechanical characteristics to withstand the task for which it is designed and that have a lower cost than the stainless steel. Because the use of plastic, which would drastically reduce the price of the piece as it is the material used in the rest of the product, has been ruled out by having insufficient mechanical properties, has opted for the use of aluminum, a material commonly used in small appliances and with sufficient mechanical characteristics. After using the Apriori software to estimate the price of the new piece with the new modifications that affect the functionality, the change of material allows a reduction of $0.82 even though the new piece is more complex, needs more material and is composed of more parts. Thanks to a rough estimate of the sales of this product throughout the year, it is estimated that this improvement would allow the company to increase profits by $123,000.

	Price per piece		**Total price**
Original piece	$1.52		$1.52
Modified piece	Inner piece	$0.23	$0.7
	Outer piece	$0.26	
	Button	$0.16	
	Spring	$0.05	
		Save	$0.82

Also, a fictitious design of experiment has also been perfomed which, if a real experiment with clients is realized, allows to determine whether the changes implemented satisfy the client and in which proportion each of the factors such as the material of the handle or its functionality affect such customer satisfaction.

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Introduction

The main objective of this project is the redesign of an existing product in the market and after making various analyzes on its functionality and production, propose and make various changes that allow an improvement in the original product. The product to be studied and improved is a vacuum cleaner of the Dirt Devil brand to which several analyzes will be applied, such as a first study on its parts and materials, then study the market, the needs of customers, manufacturing processes and assembly and an analysis of production costs.

Once detected the weak points and the possibilities of improvement, a new design of the product and a first physical prototype will be carried out thanks to 3D printing, which will allow us to test these new changes. The main objective will be to improve the processes of manufacturing and assembly of the original product, which will allow savings in production costs and, therefore, an increase in the profits of the company. In addition, we will try to improve the functionality of the product that allows to get a differentiation with similar products of the competition.

1. Disassemble and Bill of Materials

1.1 Disassemble

Figure 1: Disassembly picture

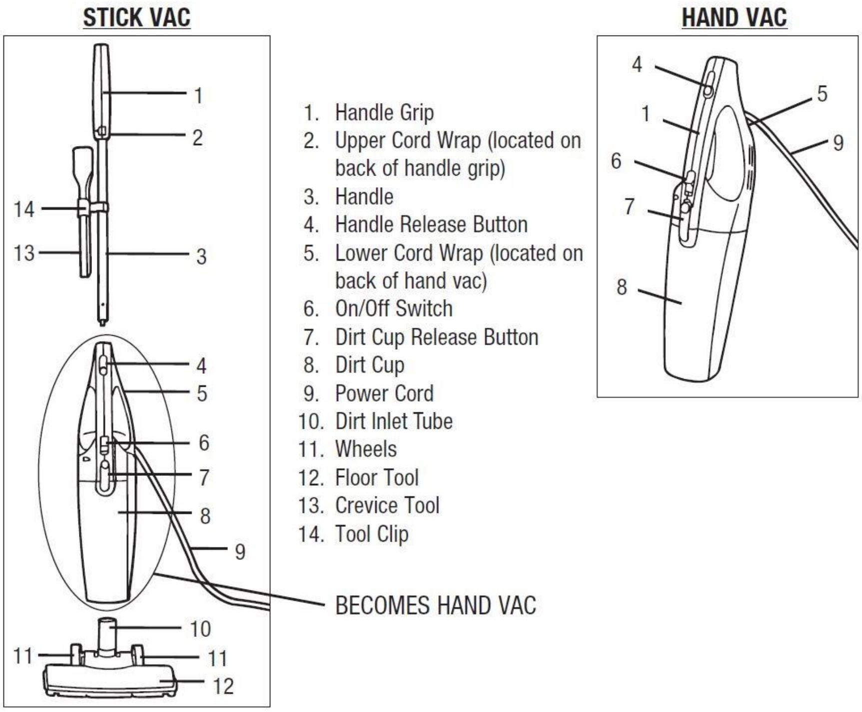


Figure 2: Main parts (source: Dirt Devil)

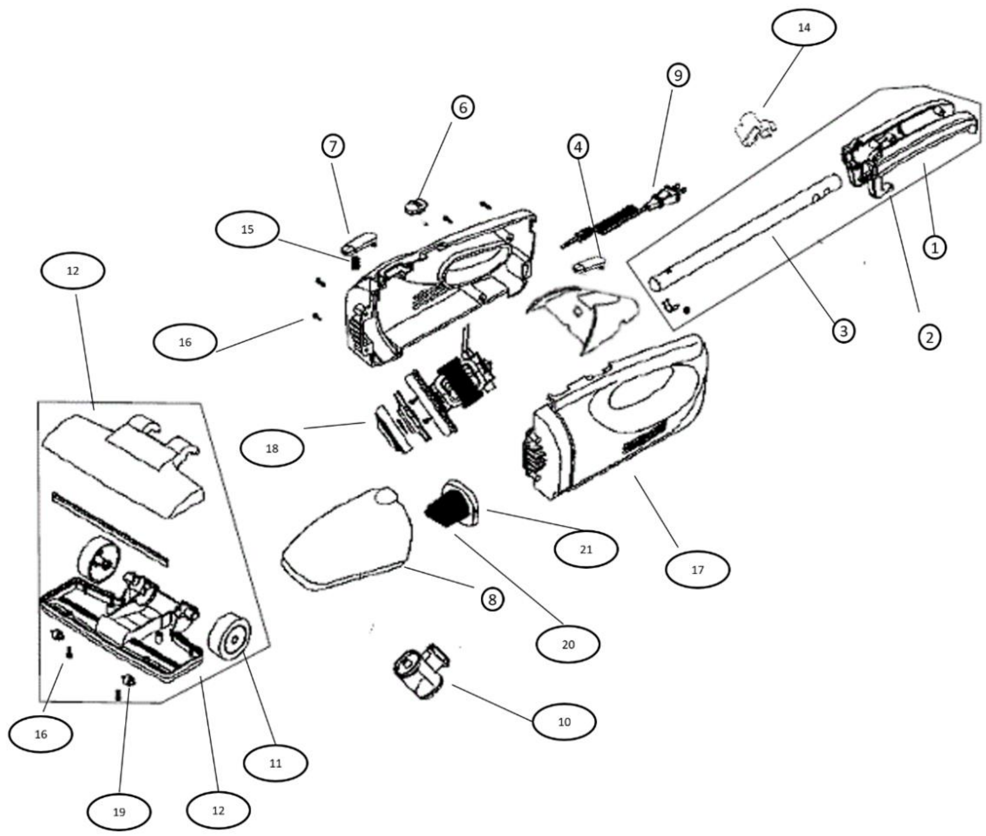


Figure 3: Exploited view (source: www.partswarehouse.com)

1.2 Bill of Materials

Part number	Part Name	Quantity	Manufacturing Process	Material
#1	Handle Grip	1	Injection Molding	Plastic-ABS
#2	Upper Cord Wrap	1	Injection Molding	Plastic-ABS
#3	Handle	1	Molding	Stainless Steel
#4	Handle release button	1	Injection Molding	Plastic-ABS
#5	Lower Cord Wrap	1	Injection Molding	Plastic-ABS
#6	On/Off Switch	1	Injection Molding	Plastic-ABS
#7	Dirt Cup Release Button	1	Injection Molding	Plastic-ABS
#8	Dirt Cup	1	Injection Molding	Plastic-ABS
#9	Power Cord	1	Wire Drawing	Plastic and Copper
#10	Dirt Inlet Tube	1	Injection Molding	Plastic-ABS

#11	Wheels	2	Injection Molding	Plastic-ABS
#12	Floor Tool Case	2	Injection Molding	Plastic-ABS
#13	Crevice Tool	1	Injection Molding	Plastic-ABS
#14	Tool Clip	1	Injection Molding	Plastic-ABS
#15	Spring	1	Machining	Stainless Steel
#16	Screw	17	Thread Rolling	Stainless Steel
#17	Hand vacuum case	3	Injection Molding	Plastic-ABS
#18	Motor	1		
#19	Small wheels	2	Injection Molding	Plastic-ABS
#20	Filter Case	1	Injection Molding	Plastic-ABS
#21	Filter	1	Injection Molding and Knitting	Plastic and Cotton

Table 1: Bill of Material

2. Technical specifications and market data

2.1. Technical specifications

Technical specifications	
Assembled Unit Depth	17.78 cm
Assembled Unit Height	101.6 cm
Assembled Unit Width	15.24 cm
Assembly Required	Some assembly, but no tools required
Auto Cord Rewind	No
Cordless	No
Cord length	4.88m
Bagless	Yes
Bin Capacity	0.35 L
Brushed Edge Cleaning	Standard
Cleaning Path	22.86 cm
Detachable Hand Vac	Yes
Detachable Handle	Yes
Dirt Cup	Easy Empty
Dirt Path	Center Dirt Path
Dry Nozzle Brush Type	Hard Floor Straight Suction
Filter Type Part Number	F25
Filtration Features	Replaceable, Rinseable
Grip Type	Standard Grip Handle
Handle Material	Plastic
Headlight	No
Lightweight	Yes
Motor Amps	1.25 Amps
Voltage	120 V
Product weight	1.723 Kg
Removable Nozzle	Yes

Table 2: Technical specifications

2.2. Market data

The market of commercial vacuum cleaners for the home is very wide and competitive, since the need for a vacuum cleaner in each house makes this product indispensable. This market is growing due to bigger public awareness about health and hygiene, an increase in people's incomes, a rise in the use of carpets and better living standards in developing economies, such as China, India, South Korea, and others. There is a large type of vacuum cleaner in the market, with cable, cordless, automatic, portable, industrial... that allows users to choose the product that best suits their needs.

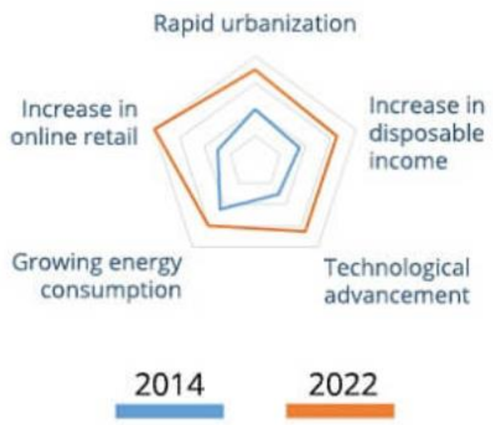


Figure 4: World household vacuum cleaners market top impacting factors (source: Verma, Preksha. (2016). Household Vacuum Cleaners Market, Global Opportunity Analysis and Industry Forecasts, 2014 – 2022)

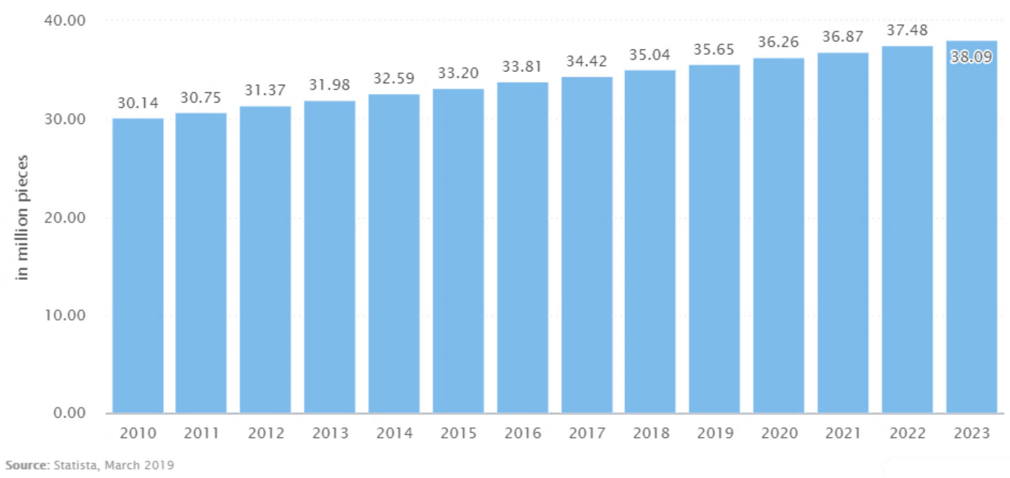


Figure 5: Volume in million pieces in the market for Vacuum Cleaners (source: www.statista.com)

Despite the large number of products and brands that exist in the market, the global household vacuum cleaners market was valued at $11,968 million in 2015 and is expected to reach $16,657 million by 2022, growing at a CAGR (Compound annual growth rate) of 4.7% over the forecast period. In addition, this market is changing with the appearance of new types of automatic vacuum cleaners, however, for now these types of vacuum cleaners are expensive and have a small market volume.

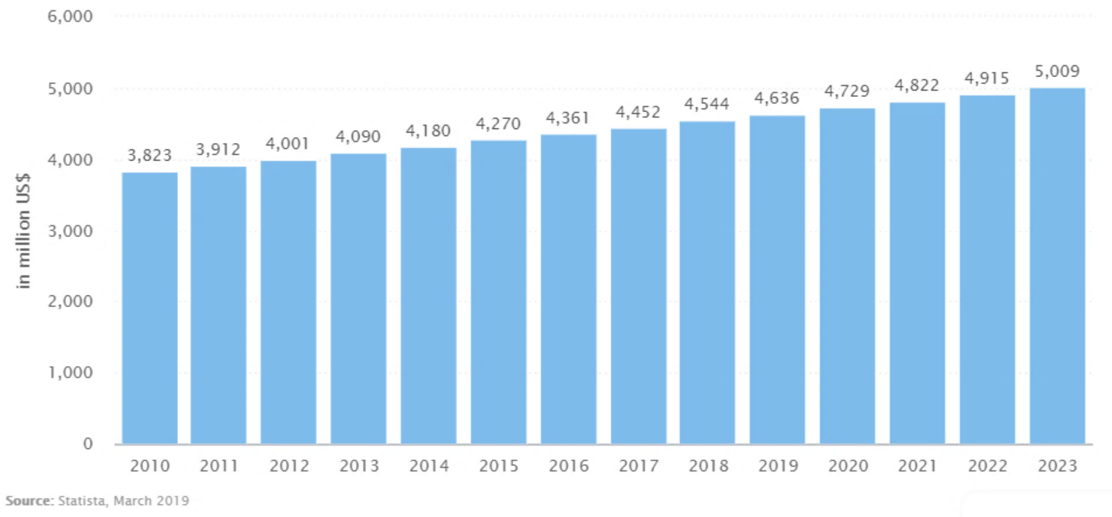


Figure 6: Revenue in the Vacuum Cleaners segment (source: www.statista.com)

The sales of the vacuum cleaners are divided between online and offline sales. Both sales methods are growing, off-line sales because they are present in supermarkets, hypermarkets and retail stores, in addition to the preference of many people for offline store experience and direct contact with experts. At the same time, online sales are growing due to the development of e-commerce and the wide variety of products that are offered in large online sales platforms.

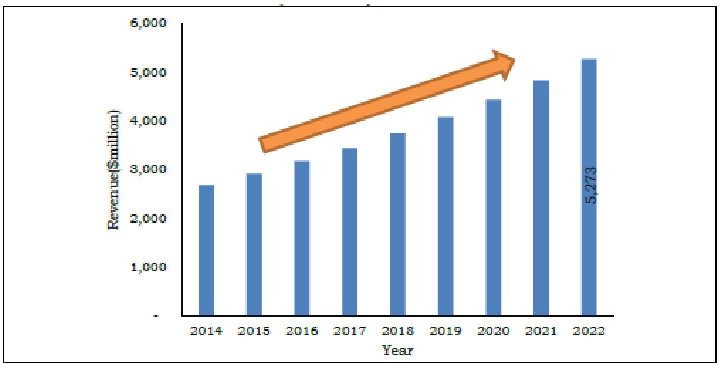


Figure 7: Predicted revenues from the online sale of vacuum cleaners, 2014–2022 ($Million)

(source: Verma, Preksha. (2016). Household Vacuum Cleaners Market, Global Opportunity Analysis and Industry Forecasts, 2014 – 2022)

Asia dominates in the sales section by countries, due to the development they are experiencing, a large population and the consumer preference to change from conventional cleaning techniques to automated cleaning solutions. In the same way, growing Latin American countries, such as Brazil, are in the top positions of the sales ranking.

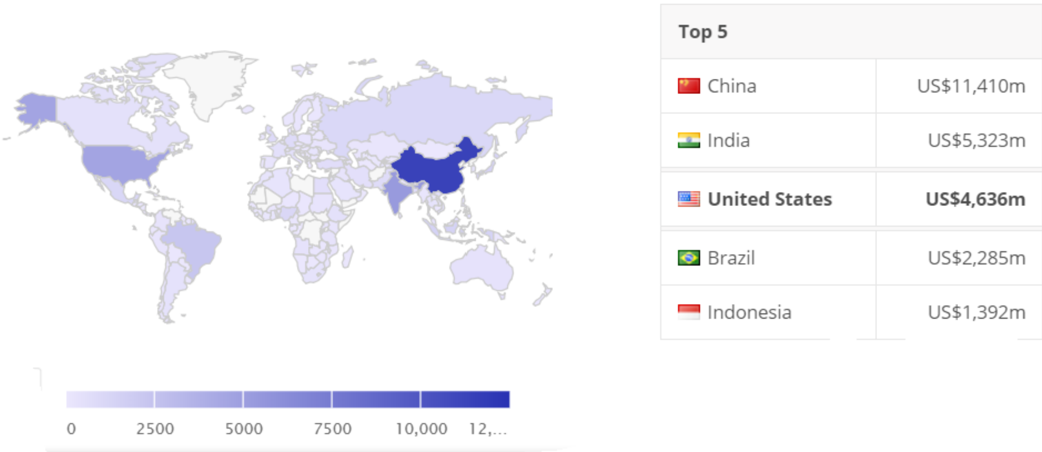


Figure 8: Global Comparison – Revenue in million US$ (source: www.statista.com)

Within this market, there are other submarkets according to the different types of vacuum cleaners. In this case, our product can be classified as a portable vacuum cleaner with cables or an upright stick vacuum. This type of vacuum cleaner is characterized by its low weight, which makes it portable, and the need to be always connected to the electrical network for its operation. In addition, in turn, within this classification you can find two completely different markets, one that is characterized by a great power of the engine and therefore, a better quality in the aspirate, and another, in which our product is framed, which prioritizes a lower sales price.

A large number of brands compete in this sector, being as shown in the figure 9, Dirt Devil is the second brand in the United States with the largest market share. Some of the products with which our product competes are detailed in the following table:

Model	*Black & Decker Lite BDASL202*	*BISSELL PowerSwift™ 18082*	*Eureka NES210*	*Hoover FH50700*	*Dirt Devil SD20000RED*
					
Capacity	2 L	1.5l	No data	1.9 L	0.35 L
Weight	4kg	4.5kg	1.8kg	5.44kg	1.723 Kg
Cordless	No	No	No	No	No
Power	7 Amps	7.5Amps	2 Amps	No data	1.25 Amps
Price	$69.99	$64.99	$29.99	$89.99	$19.99

Table 3: Competition

Dirt Devil, Hoover and Oreck are companies that belong to the same corporate brand, TTI Floor Care, so they have a 32% volume market share of an almost $5 billion industry, according to Euromonitor. Dirt Devil is the company focused on low cost vacuum cleaners, being one of the cheapest vacuum cleaners in the market, thus reaching a public that does not need a high-powered vacuum cleaner and does not want to spend a large amount of money.

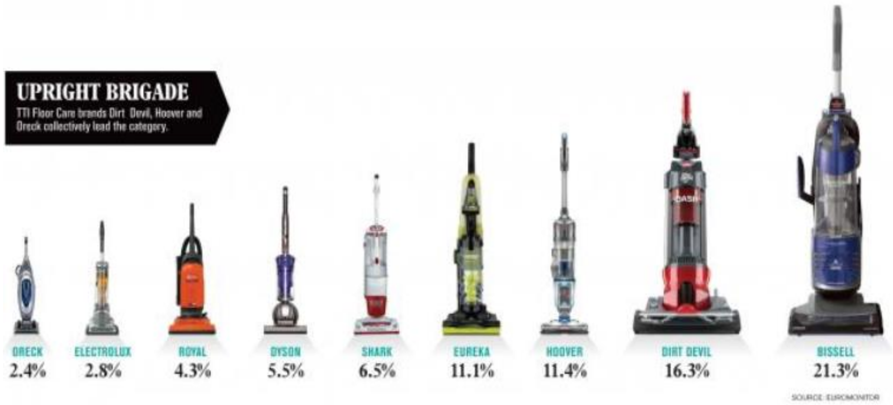


Figure 9: Market share (source: Euromonitor)

3. Estimation of the Manufacturing Cost.

Manufacturing cost is the sum of costs of all resources consumed in the process of making a product. These costs can be classified into three different categories: direct materials, direct labor and manufacturing overhead. Direct materials are all the items consumed or put into production during the year, including the cost of parts, components, containers, all raw materials, cost of products bought to other companies, cost of fuels consumed, etc. Direct labor, which are the wages and fringe benefits earned by the individuals who are physically involved in converting raw materials into a finished product and manufacturing overhead, which includes indirect costs as repairs, depreciation of the equipment, electricity, transportation or maintenance.

Although all these costs data are confidential, and it is difficult to know the total cost of manufacturing, many of the manufacturers use the Keystone price method whereby the product is priced for resale at an amount that is double the cost of manufacturing the product. Applying this method, as this product, the SD20000RED vacuum, is sold for an average price of $ 19.99, the manufacturing cost must be around $10. It is possible that, due to the large number of products and competitors that exist in the market, the company has decided to reduce the profit margin to achieve a lower sales price that increases the number of sales, so the manufacturing cost could be a bit higher than the $10 indicated by the Keystone method.

This production cost is as low as it is due to the use of low-cost materials and specific manufacturing techniques. Much of the product is made of plastic, specific ABS, and thanks to the plastic injection molding, a cheap product is obtained, with great efficiency, a fast production, generating little waste. ABS plastic is one of the cheapest plastics and with better characteristics of the market, and that is the reason why most of the small appliances are made of this material, in addition, as it is the main material with which most of the pieces of the product are made, a large-scale purchase of this material can be done and thus a better price per kilogram can be achieved. Also, plastic injection molding is known as the most used and efficient technique for plastic modeling since it combines a high speed of production with the possibility of creating complex objects at a relatively low price. This low price, despite a large initial investment, is achieved thanks to the fact that it produces very little waste material and that it does not need a big amount of labor since most processes are automatic.

In addition, the product is designed in a way that a lot of items purchased from other companies is not needed, allowing great savings in costs. As for the assembly, most unions do not need additional elements and only a small amount of screws are used, this allows, in the first place, a saving in the cost and time of assembly and, by using screws of the same, a purchase of greater quantity and, therefore, a reduction in the costs of purchasing products can be achieved.

4. Quality Function Deployment, QFD

When designing a product it is necessary to make a preliminary study of the market to know the needs of customers, market opportunities and competition. One of the tools that allows you to decide how to make the product according to these parameters is the QFD (Quality Function Deployment) matrix. The QFD matrix or house of quality is a tool to identify what the customer needs and translate them into specific plans and engineering specifications to produce products to meet those needs. In addition to listening to “the voice of customers”, this matrix allows us to know where our model stands in the market compared to other brand models of similar specifications.

Once the matrix is completed, we can know the desires and priorities of the customers and trace the product development plan according to the data provided by the customers, the competition and how an improvement of each of the technical specifications influences the needs of the customers. In the left column the customer requiriments are indicated besides their importance to the customer on a scale of one to five, while in the upper part of the table are the technical characteristics.

1		17%	8	9	Lightweight
2		17%	8	9	Great performance
3		13%	6	3	Durable
4		10%	5	9	Bin capacity
5		8%	4	9	Conversion to a hand vacuum
6		15%	7	9	Portable
7		21%	10	9	Low cost

Table 4: Customer requirements

1	2	3	4	5	6	7	8	9	10
▲	▼	◇	◇	◇	▲	▲	▼	▲	▲
Suction Power	Weight	Size	Cordless	Removables parts	Cord Lenght	Material Quality	Manufacturing Cost	Bin Volume	Number of accessories

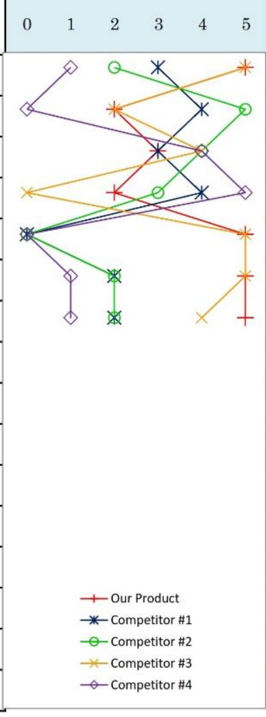
Table 5: Functional Requirements

To fill in the rows of customer requirements it is necessary to carry out some type of survey or meetings with clients to obtain feedback. The center grid of the matrix shows the relationship that each customer requirement has with each technical specifications, this elationship can be strong, with a weight of 9, moderate, with a weight of 3 or weak, with a weight of only one. In the same way on the "roof" of the table are indicated the potential conflicts between technical specifications, these correlations can be positive, if when the value of a technical specification increases the other also increases, negative if the change of one parameter affects in a contrary way the other or there may not be any correlation between both parameters if when modifying a value the other is not affected. The right part indicates with a value between 1 (poor) and 5 (excellent) how the product to be manufactured and the models of the competition satisfy each one of the requirements of the clients. It also shows a trending line that indicates where our model stands in the market.

Table 6: Competition

Customer Competitive Assesment

Our Product: Dirt Devil SD20000RED	Competitor #1: *Black & Decker Lite BDASL202*	Competitor #2: *BISSELL PowerSwift™*	Competitor #3: *Eureka NES210*	Competitor #4: *Hoover FH50700*	Row #
5	3	2	5	1	1
2	4	5	2	0	2
3	3	4	4	4	3
2	4	3	0	5	4
5	0	0	5	0	5
5	2	2	5	1	6
5	2	2	4	1	7
					8
					9
					10
					11
					12
					13
					14
					15
					16

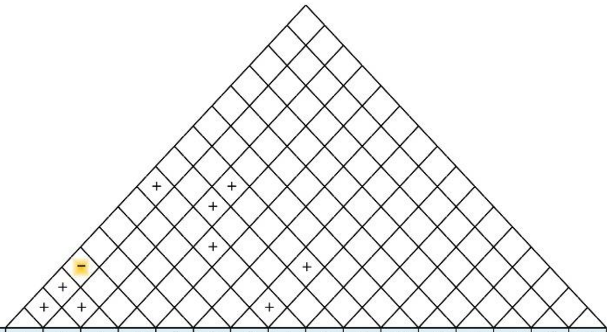


QFD: House of Quality
Project:
Revision:
Date:

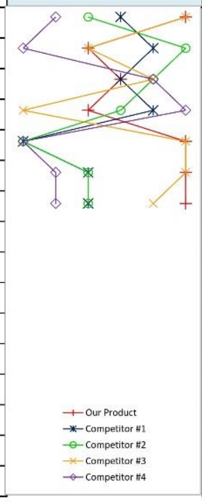
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Customer Competitive Assesment						Row #
					Direction of Improvement	▲	▼	◇	◇	◇	▲	▲	▼	▲	▲													
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)	Suction Power	Weight	Size	Cordless	Removables parts	Cord Lenght	Material Quality	Manufacturing Cost	Bin Volume	Number of accessories							Our Product: Dirt Devil SD20000RED	Competitor #1: *Black & Decker Lite BDASL202*	Competitor #2: *BISSELL PowerSwift™*	Competitor #3: *Eureka NES210*	Competitor #4: *Hoover FH50700*	0 1 2 3 4 5	Row #
1		17%	8	9	Lightweight	○	●	●						▽								5	3	2	5	1		1
2		17%	8	9	Great performance	●	○	○	○													2	4	5	2	0		2
3		13%	6	3	Durable	○			○	○		○	○									3	3	4	4	4		3
4		10%	5	9	Bin capacity		○	○						●								2	4	3	0	5		4
5		8%	4	9	Conversion to a hand vacuum		○			●												5	0	0	5	0		5
6		15%	7	9	Portable		●	●	○	○	●			▽								5	2	2	5	1		6
7		21%	10	9	Low cost	●	▽	○	●			●	●									5	2	2	4	1		7
8																												8
9																												9
10																												10
11																												11
12																												12
13																												13
14																												14
15																												15
16																												16



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Target	4 Amps	2 Kg	100x25cm			6m		< $10	1,5L	2						
Max Relationship	9	9	9	9	9	9	9	9	9							
Technical Importance Rating	425	408,3	425	318,8	156,3	131,3	225	225	125	0						
Relative Weight	17%	17%	17%	13%	6%	5%	9%	9%	5%	0%						
Weight Chart																
Our Product	2	5	5	0	5	3	3	4	2	4						
Competitor #1	4	3	3	0	3	4	3	3	4	2						
Competitor #2	4	2	3	0	3	5	4	3	3	4						
Competitor #3	4	5	5	0	5	4	3	4	0	4						
Competitor #4	5	1	2	0	3	4	4	3	4	2						
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Technical Competitive Assesment

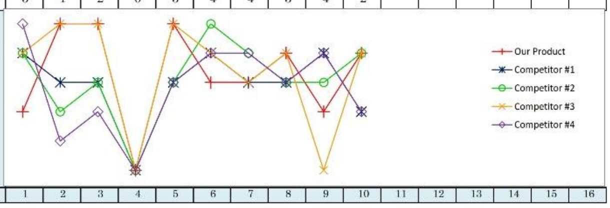


Table 7: QFD matrix

This preliminary version of the QFD of our product indicates, through the relative weight of each specification, that the most important technical specifications that will allow us to satisfy the main requirements of the clients are the suction power, the weight and the size. In addition, the matrix shows how our product obtains a high score against the competition in the main requirements and technical specifications, except for the suction power that directly affects the performance of the vacuum cleaner.

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	▲	▼	◇	◇	◇	▲	▲	▼	▲	▲						
	Suction Power	Weight	Size	Cordless	Removables parts	Cord Lenght	Material Quality	Manufacturing Cost	Bin Volume	Number of accessories						
Target	4 Amps	2 Kg	100x25cm			6m		< $10	1,5L	2						
Max Relationship	9	9	9	9	9	9	9	9	9							
Technical Importance Rating	425	408,3	425	318,8	156,3	131,3	225	225	125	0						
Relative Weight	17%	17%	17%	13%	6%	5%	9%	9%	5%	0%						
Weight Chart																
Our Product	2	5	5	0	5	3	3	4	2	4						
Competitor #1	4	3	3	0	3	4	3	3	4	2						
Competitor #2	4	2	3	0	3	5	4	3	3	4						
Competitor #3	4	5	5	0	5	4	3	4	0	4						
Competitor #4	5	1	2	0	3	4	4	3	4	2						

Technical Competitive Assesment

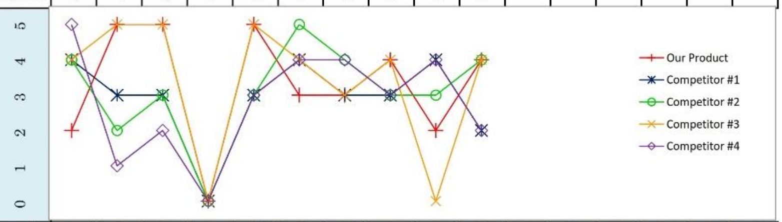


Table 8: Functional Requirements

Because the improvement of the motor would significantly affect the cost of production and therefore, the sale price of the product will not consider strengthening this specification, since the price is the differentiator element from the competition because it is in the low-cost sector. Due to the fact that with this matrix there does not seem to be a clear improvement direction, a deep analysis will be needed to look for new requirements from the clients that complete the matrix and help us to improve our product.

5. Customer requirements

A very important part in the analysis of a product and to know the possibilities of improvement is to know what are the requirements and needs of customers. To know this, it is necessary to carry out some type of survey or extract information from the reviews that people make in our product as well as in similar products of the competition. This second method is the one that has been used to create a list with the requirements of the clients and their importance from 1 to 10.

Customer needs: Customer Importance (1-10)

1. Size
   a. Small depth...3
   b. Small width...3
   c. Adequate Height...8
   d. Lightweight...9
   e. Easy to store...8
2. Power
   a. High suction power..7
3. Portable
   a. Possibility of disassembly 7
   b. Convertible to a hand vacuum............................6
   c. Cordless 7
   d. High length of the cord.......................................7
4. Aesthetics
   a. Aesthetically pleasing...6
5. Accessories
   a. Crevice tool...7
   b. Floor tool 9
6. Capacity
   a. Bin capacity 6
7. Surfaces
   a. Wood..7
   b. Rug...8
   c. Ceramic tiles 7
8. Material
   a. Material quality...6
   b. Impact resistant...7
   c. Durability..9
   d. Surface finish..4
9. Cost

a. Price 9

10. Shape and ergonomics

a. Stability..7

b. Handle comfort 4

c. Extendable handle...9

The main requirements that were not previously in the matrix and that therefore have to be added to a new version are the incorporation of an extendable handle, the ease of storage and the possibility of using the vacuum cleaner on different surfaces. When new requirements are added, technical aspects or specifications will appear in which the current product weakens with respect to the competition or that allows creating a differentiating element with the rest.

6. Direction for Improvement

After carrying out a new analysis, this has thrown new requirements from customers that had not been taken into account in the previous version of our QFD matrix. Once these new requirements have been added, the table has been completed and a study of how our product and the compitition behave against these new requirements has been realized, the direction of improvent of the product can be drawed up.

Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Suction Power	Weight	Size	Cordless	Removables parts	Cord Lenght	Material Quality	Manufacturing Cost	Bin Volume	Number of accessories							Our Product: Dirt Devil SD20000RED	Competitor #1: *Black & Decker Lite BDASL202*	Competitor #2: *BISSELL PowerSwift™*	Competitor #3: *Eureka NES210*	Competitor #4: *Hoover FH50700*
9	9	Extendable handle			•														0	0	0	0	0
8	9	Easy to store			•		•				▿	▿							4	2	2	4	2
7	9	Suitable for different surfaces	○									•							3	4	4	3	5

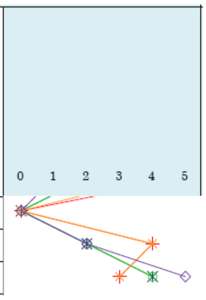


Table 9: Customer requirements

In these three new requirements our product can be improved, the extendable handle is a feature that none of the competitors possesses and which, in turn, is of great importance to many customers, so its incorporation would be a big difference with the rest and could mean a big increase in sales. With regard to the possibility of being used in different surfaces, our product is behind the competition so it should also be an aspect to be studied in subsequent analyzes.

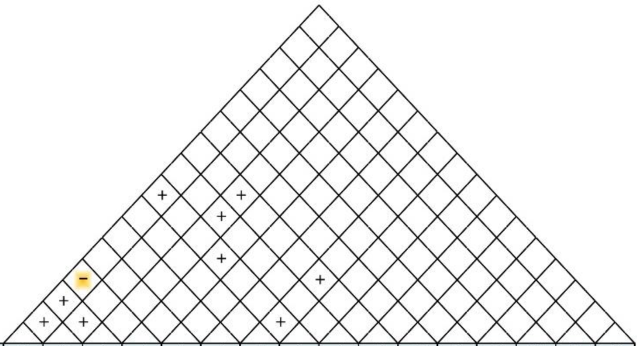
After adding these new data, the size becomes the technical specification with more weight in the study, so reducing this size will allow us to improve many of the demands of our customers. Once the weaknesses of our product are known, which is what the client wants and what aspects need to be focused on improving, it is necessary to accomplish different analyzes to see the improvement options and the feasibility of them.

QFD: House of Quality
Project:
Revision:
Date:

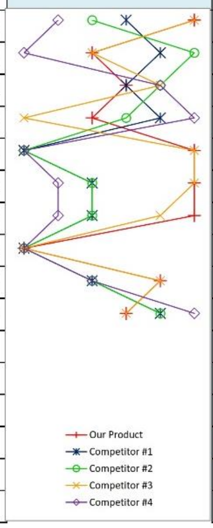
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Suction Power	Weight	Size	Cordless	Removables parts	Cord Lenght	Material Quality	Manufacturing Cost	Bin Volume	Number of accessories	11	12	13	14	15	16	Our Product: Dirt Devil SD20000RED	Competitor #1: *Black & Decker Lite BDASL202*	Competitor #2: *BISSELL PowerSwift™*	Competitor #3: *Eureka NES210*	Competitor #4: *Hoover FH50700*	Row #
					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Customer Competitive Assesment					
					Direction of Improvement	▲	▼	◇	◇	◇	▲	▲	▼	▲	▲												
1		11%	8	9	Lightweight	○	●	●						▽								5	3	2	5	1	1
2		11%	8	9	Great performance	●	○	○	○													2	4	5	2	0	2
3		8%	6	3	Durable	○			○	○		○	○									3	3	4	4	4	3
4		7%	5	9	Bin capacity		○	○						●								2	4	3	0	5	4
5		6%	4	9	Conversion to a hand vacuum		○			●												5	0	0	5	0	5
6		10%	7	9	Portable		●	●	○	○	●			▽								5	2	2	5	1	6
7		14%	10	9	Low cost	●	▽	○	●			●	●									5	2	2	4	1	7
8		13%	9	9	Extendable handle			●														0	0	0	0	0	8
9		11%	8	9	Easy to store			●		●				▽	▽							4	2	2	4	2	9
10		10%	7	9	Suitable for different surfaces	○									●							3	4	4	3	5	10
11																											11
12																											12
13																											13
14																											14
15																											15
16																											16



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Target	4 Amps	2 Kg	100x25cm			6m		< $10	1,5L	2						
Max Relationship	9	9	9	9	9	9	9	9	9	9						
Technical Importance Rating	312,5	272,2	495,8	212,5	204,2	87,5	150	150	94,44	98,61						
Relative Weight	15%	13%	24%	10%	10%	4%	7%	7%	5%	5%						
Weight Chart																
Our Product	2	5	5	0	5	3	3	4	2	4						
Competitor #1	4	3	3	0	3	4	3	3	4	2						
Competitor #2	4	2	3	0	3	5	4	3	3	4						
Competitor #3	4	5	5	0	5	4	3	4	0	4						
Competitor #4	5	1	2	0	3	4	4	3	4	2						

Technical Competitive Assesment

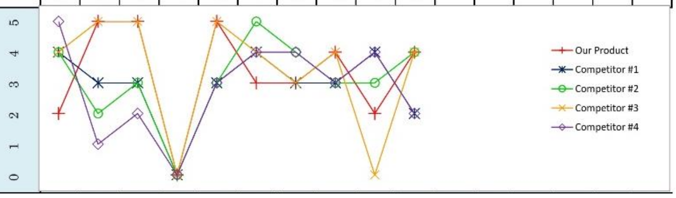


Table 10: QFD matrix

7. Areas of Improvement

After carrying out the previous analyzes, some improvable aspects have appeared. After seeing what are the requirements that customers want and after analyzing the current characteristics of our product, the improvement direction seems to be aimed at minimizing the weight and size, in order to achieve an easy-to-store product, while maintaining the performance and versatility of the vacuum cleaner and above all, the price.

Currently, our product is one of the smallest and lightest vacuum cleaners on the market, so these requirements are difficult to improve, in addition to that, a change of design and material would be necessary, which would mean new studies on the design, testing and possibly, new machines, so it would not be feasible in the short term. Another aspect of the product that can be improved is the motor power, therefore, the performance of the vacuum cleaner. However, the only way to improve the suction power is a change of motor to a more powerful one, which would mean a higher price of the product. As the price is one of the most important requirements for customers, in addition to our vacuum cleaner is in the low-cost sector which means that the price matters more than the performance of the product, a change of motor is also unfeasible.

Other aspects that could be improved is the incorporation of an extendable handle or the creation of new accessories. An extendable handle would allow an improvement of the comfort to be able to adapt to the different heights of the people and, in addition, it would allow to store the product of a simpler form, occupying less space, without needing disassembling the product, which can cause the breakage of pieces if it is not done correctly. Adding accessories to use the vacuum cleaner on different surfaces would give more value to the product, however, the current product already incorporates accessories for floors and corners, besides being able to be used as a hand vacuum cleaner, which is enough for most of the audience for whom this product is focused, so adding accessories would increase the cost and for many people would not increase the functionality.

On the other hand, an optimization of the manufacturing processes methods would suppose a reduction of the cost of the product, and therefore, or a greater profit margin or a lower sale price. For this it is necessary to study the methods and processes that are currently carried out to manufacture this product.

First, most parts are made of plastic through injection molding, this process basically consists of producing parts by injecting molten plastic into a mold. Therefore, the first step is the creation of a mold, this part of the process is the most expensive because it takes a long time to get the design, get precise tools that perform the mold with the necessary precision and perform a large amount of tests before starting to create the pieces. Once the mold is created, a machine melts the plastic, and inserts it into the mold where a sprue guides the molten plastic from the nozzle to the cavities through a system of channels called runners, where it takes the desired shape. The main advantages obtained through this process is that it allows a mass production, obtaining identical objects while generating low scrap rates which allows creating low cost pieces once the initial investment has been made.

Currently, mold injection is the most used process to create plastic parts and is the most appropriate for the parts that make up our product, however, a reduction in the cost of manufacturing can be achieved if the process is optimized. One way to optimize it, is using hot runners instead of cold runners, the main advantage that heating the runners gives us is that it reduces wasted plastic because with cold runners, the channel needs to be large and more plastic is needed. Changing mold design can save a lot of money if done correctly, however, as stated before, creating a new mold is a very expensive process, therefore, in many cases it is preferable to maintain the design and reuse the plastic waste.

Other ways to reduce the cost of manufacturing is to reduce the price of materials or the number of pieces used. The product is made mostly of plastic, specifically ABS, which is one of the most used plastics in this type of appliance due to its low cost and its easy use in the injection molding process, so a change of material in these pieces will not be considered. Although the product is made mostly of plastic, the handle is made of stainless steel. If the piece could be redesigned to make it also in plastic, either with the same plastic used or with another type of more resistant plastic, it would be possible to reduce the cost since it would not need specific machines for steel and, would allow the purchase of more volume of plastic to the same seller and get a better price per kilogram.

All the pieces that form the product seem to be indispensable and, therefore, hardly eliminated, there also seems to be no way of joining pieces and therefore reducing the number of pieces. As for the assembly, this is very basic and is done only through screws, so it does not seem possible to reduce spending in this process.

8. Product Design Specifications (PDS)

1. SAFETY: Being a product that must be connected to the electrical network needs protection against short circuits that could cause the product to burn. In addition, since it is a product designed for the home, it is preferable that it does not contain small pieces that can be ingested by children or pets.

2. ERGONOMICS: The product can be used for long periods of time, so consumer comfort is very important. As the vacuum cleaner is designed to be used standing up, it is very important that the height is adequate so as not to cause back pain. Also, the handle should be comfortable to the touch so that it does not disturb when used for several hours.

3. COMPANY CONSTRAINTS: The manufacturing company, Dirt Devil, is a company dedicated exclusively to the manufacture and sale of vacuum cleaners, so the product fits perfectly into the philosophy of the company. In addition, this company is part of a parent company that includes several companies dedicated to tools for cleaning floors. This allows the company to use parts for several models as well as the purchase of materials and parts in a massive way, getting a better price. In addition, when manufacturing similar products, in the same production plant different models can be created by sharing machines and workforce.

4. AESTHETICS: Aesthetics does not affect the performance of the product, however, a good finish can help sales as the first impression is very important for potential buyers. In addition to the shape, color is very important when it comes to increasing the sales of a product.

5. INTELLECTUAL PROPERTY: Although the company owns more than 50 patents, none is for this product.

6. TESTING: It is necessary to test all the products once they are finished in order to verify that the electrical part is working correctly and at the desired power. The motors and other electrical pieces are bench tested before installation. Also, assembly-line workers can reject any imperfect parts or partially assembled machines they find.

7. PROCESSES: Plastic parts are manufactured with injection molding and the stainless-steel handle is manufactured by cutting and bending steel sheets. Other pieces are bought at external companies.

8. SIZE & WEIGHT: The size and weight are very important to make the vacuum cleaner portable, besides, the height also affects the ergonomics of the product. To ensure that the packaging is as small as possible, which allows a lower transport cost, the vacuum cleaner can be disassembled to achieve a reduced size.

9. MAINTENANCE: To maintain performance, filter should be changed every 3-6 months. No more maintenance is needed since the motor and brushroll are equipped with bearing which contain enough lubrication for their lifetime.

10. PERFORMANCE: The main function of the vacuum cleaner is to suck the dirt from the floor and for this a sufficient power of the motor is needed to achieve it. The suction power is measured in amps or in Watts. The amperage rating designates the maximum amount of electrical current used by all the vacuum cleaner's electrical components when operating. As our product is found in the low-cost vacuum sector, a powerful motor is not necessary as it would drastically increase the price of the product.

11. LIFE IN SERVICE: The product has a one-year warranty but if used correctly it should last longer.

12. SHIPPING: The product is manufactured in Hong Kong, so it is necessary to send it to the United States possibly through ships. When the product arrives at an American port it must be sent to the American headquarters located in Charlotte, possibly through trucks. Finally, the product is sent to sellers as amazon or directly to the customer, also through trucks.

13. PACKAGING: The disassembled product in a cardboard box together with the accessories and the instruction manual. The product does not come with any additional protection. The total weight of the packaged product is 4.25 pounds and the measures are

14. COMPETITION: There is a lot of competition in the vacuum cleaner market, however, this product differs from the rest in the price, because it is possibly the lowest priced vacuum that can be found in the market. There is a wide variety of products on the market according to the needs of each person.

15. MANUFACTURING FACILITY: The company has its own facilities where they can manufacture their products, and since they belong to a

larger company, they can share facilities with the rest of the companies that are part of the parent company.

16. MATERIALS: Currently, to make this product only need two types of materials, plastic and steel for the handle. By using the same material for most of the pieces, Larger quantities of raw material can be bought, which allows you to get a better price. In addition, the materials used are very common so there is no problem of material supply.

17. PRODUCT LIFE SPAN: Although there is a great variety of products and companies, and new models come out every year, the life in the market of a vacuum cleaner can be several years since there are no great technological advances that can make the product be superseded.

18. STANDARDS: The company sells internationally to the United States and Europe, so it must be subject to international standards and those of each country.

19. CUSTOMER: The product is focused on an audience that does not need a high-powered vacuum cleaner and does not want to pay a lot of money for it.

20. QUALITY & RELIABILTY: It is expected that the product performs satisfactorily the work for which it is designed, for which it is necessary that the motor provides the necessary power to be able to vacuum the dirt. It is also expected to last without problems for years. As the product is found in the low-cost sector, no exceptional performance or high material quality is expected.

21. DISPOSAL: The product is designed to last several years, however, some of the typical failures that can happen are electrical problems, motor failure and breakage of plastic parts. Although it is assumed that the product should last several years, being in the low-cost sector, the quality of the materials is inferior to similar products of higher price and therefore, there is a higher risk of failure. The company has technical service to resolve possible failures and are available for sale loose parts if any piece is broken.

22. MARKET CONSTRAINT: Being a product that connects to the electrical network, as it is sold in different countries in Europe and North America, it must be manufactured with different plugs and different frequencies so that it works correctly in all places.

23. TIMESCALES: From the beginning of the development until the product reaches the market, various processes are carried out that can take several years until they culminate in the finished product. Once the product is finalized, permits and accreditations are needed to be able to put it on the market.

24. SHELF LIFE: By not containing metal parts that can oxidize, the product can be stored for years without any problem.

25. ENVIRONMENT: Although ABS is not biodegradable, this material is easily recycled.

26. TARGET PRODUCT COST: For plastic injection to be profitable, it is necessary to create a large number of parts, since machines and molds are expensive. Once the machines are amortized, the production cost of each product is very low, which allows a low sale price to be assumed. As for competitors, the biggest difference is the cost of the engine that represents a large percentage of the total cost of the product.

27. QUANTITY: It is a product that is mass produced as it is sold in many parts of the world and through large marketers such as Amazon or Walmart.

28. ETHICS & SOCIETY: Some of the values that the company advertises on its website are:
    - Doing the Right Thing
    - Treating Each Other With Integrity and Respect
    - Building Strong, Trusted Relationships
    - Giving Back
    - Encouraging Innovative Spirit
    - Exceeding Customer Expectations

9. Design for Manufacture and Assembly (DFMA) analysis

9.1. Manufacturing analysis

- Plastic parts: Most parts of the vacuum cleaner are made of plastic, especially the outer case. To make these pieces, the piece is first designed in computer with some CAD program, once it is designed, the mold is made in order to perform the plastic injection. Tiny plastic granules are poured into a heating tank and melted. The pellets are purchased in the desired color or colored with pigments as they melt. The melted plastic is injected under high pressure and heat into the mold, where the desired shape takes form. The plastic hardens on contact with the air as the tool opens. All the plastic parts are made with ABS, as indicated on the inside of them. ABS, also known as Acrylonitrile Butadiene Styrene, is a polymer that is composed of three different monomers: acrylonitrile, butadiene, and styrene. Depending on the amount of each monomer, the resulting material will have different characteristics, being acrylonitrile which provides chemical and thermal stability, butadiene gives the toughness and impact strength and styrene is responsible for giving the plastic a good finish. ABS is one of the most used plastics in the injection molding process due to its low melting point and its low glass transition temperature, which allow the plastic to be easily molded into different shapes. Also, some of the advantages of products made of ABS plastic are strong impact and heat resistance, high tensile strength, shock absorbance, scratch resistance and low cost. ABS plastics have limitations and disadvantages as it may burst into intense flames with high smoke generation when it is exposed to an extremely high temperatures, being the smoke very toxic. In addition, it can be damaged when exposed to sunlight for a long time and as it is a non-biodegradable plastic, if it's not recycled it will remain in the Earth for more than a thousand years before disappearing.

- Stainless steel handle: The only piece made with this material is the handle, to get the desired shape steel sheets are cut and bent. The company receives the stainless steel in the form of sheets of the thickness of the piece, in the factory the processes of cutting and bending are carried out to obtain the shape of the piece. The piece is welded, using probably the process of welding TIG, since it is the most used for this type of material and the holes are made, using dies and hole punching. Additional heat treating and cleaning processes, as annealing and polishing, are also required to achieve the quality needed. The specific characteristics of stainless steel depends on the type of alloy that is and the materials and quantities that compose it, however, some of the advantages of stainless steels are corrosion and impact resistance, heat and fire resistance, high strength, aesthetic appearance and ease of fabrication. In addition, stainless steel is a green product since it is 100% recyclable as it is not produced with any toxic material. Although up to 70% of the product used to create stainless steel come from recycled material, even if it is not recycled it will not have bad effects to the soil or groundwater.

- Filter: The filter is composed of a piece of plastic, also made with plastic injection, covered with cotton where dirt is collected. The cotton is bought and is knitted around the piece of plastic.

- Power cord: The first stage in the manufacturing process of a power cord is the wire-drawing. This process consists of reducing the size of the copper wire in order to increase ductility and conductivity. After that, heat treatments, as annealing, are applied to the coil of copper wire before starting to make the insulation. The wire passed through an extruder, where either a single or double coating of plastic is applied.

9.2. DFA analysis

The assembly and the union of the pieces to obtain the final product is one of the most expensive processes, accounting for up to 30% of a product's total manufacturing cost and up to 50% of its total manufacturing time. Therefore, it is very important to perform a DFA (Design for Assembly) analysis to optimize this process to the maximum, for this it is not necessary to make large investments and large reductions in final costs and time of assembly can be achieved, especially in products produced on a large scale.

The basic principles on which the DFA analysis is based are to reduce the number of pieces and facilitate all assembly processes. If there are less pieces in our product, less time is spent in joining them and therefore less assembly cost, in the same way, if the product can be designed with features which make it easier to handle, move, orient, insert and secure them, this will also reduce assembly time and assembly costs.

The vacuum cleaner under study is sent disassembled, on one hand the central body that serves as a hand vacuum and separately the rest of the elements: accessories for different surfaces, the metal handle and the plastic grip. This, in addition to allowing a smaller package size and therefore less transport costs, allows to reduce assembly costs by eliminating several processes. The hand vacuum cleaner is composed of the motor, the case, the buttons and the dirt cup where the filter is inserted. The first process that is carried out is the assembly of the motor and the electrical installation, for this the cables are welded and connected with the motor and the On/Off switch is placed. The motor is inserted inside the case without the need for any type of fasteners, as it is designed to fit perfectly. The buttons are placed in their respective holes without any type of fixation and the two parts of the case are joined with 9 screws. The upper cover of the case is placed thanks to the tongues that it has and that are inserted in the holes of the other part of the case. Finally, the dirty cup with the filter inside is placed with the rest of the pieces without the need of any additional element.

The floor tool consists of two plastic cases, the wheels and the tube that joins it with the vacuum cleaner. The wheels and the tube are inserted in the holes that one of the parts of the case has without the need for any fastener. The two parts of the case are assembled with 8 screws.

As it can be observed, the product is designed with the intention of reducing to the maximum the number of elements of union, that is why most of the pieces are assembled by pushing the parts' together. This method of union allows a saving in the cost because it does not need loose parts like screws, besides, it allows to save a great amount of time during the assembly.

10. CAD modeling of the existing product

After carrying out all the previous analyzes, one of the possible improvements that can be carried out is to incorporate an extendable handle that replaces the current stainless-steel handle. In addition to improving the functionality, greater comfort by adapting better to the person who uses it and the possibility of saving it easily without having to disassemble it, a possible change of material will be studied that lowers the costs of production.

The piece to be studied is a handle made of stainless steel, this handle has a triangular shape with rounded edges and hollow inside, made from a sheet of steel of the thickness of the piece. In addition, the piece has three holes, two of circular shape that completely cross the piece and a third hole of rectangular shape that only crosses one of the surfaces. The circular holes serve to fix a plastic handle that improves the ergonomics and the rectangular hole to join the handle to the hand vacuum.

A 3D simulation of the piece to be studied, created with the modeling software Solid Edge, is presented below. This simulation will allow us to know through other software, the approximate cost of making the current piece to be able to compare it with the future design.

The piece to be studied serves to convert the hand vacuum cleaner into a stick type vacuum, which allows it to be used standing up. The handle is attached to the hand vacuum cleaner through a hole in the case that allows the handle to be inserted and assembled without the need for any other element such as screws. The other end of the handle joins a plastic grip through the holes that the handle has, thanks to which it does not need additional elements for its union.

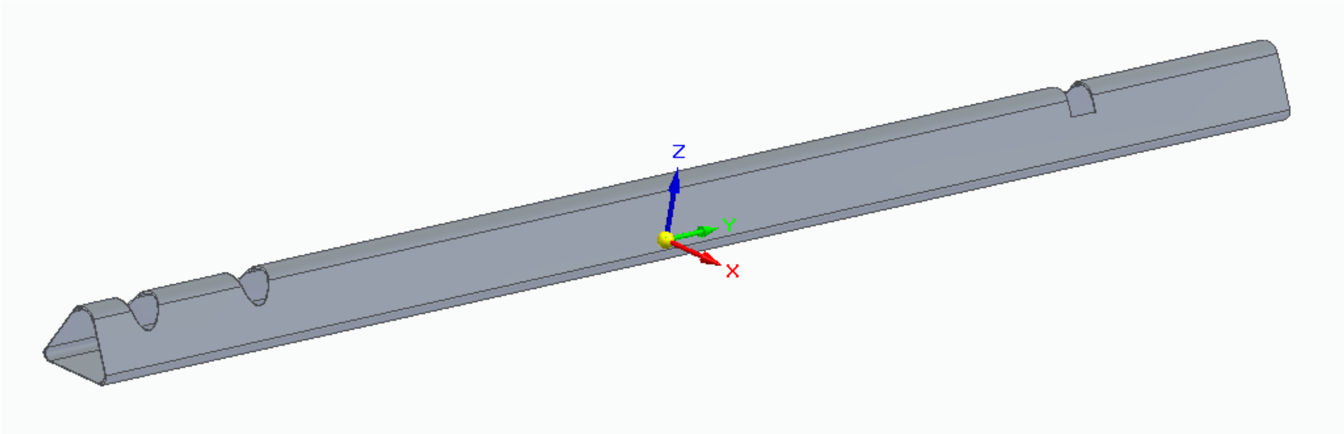


Figure 10: CAD model

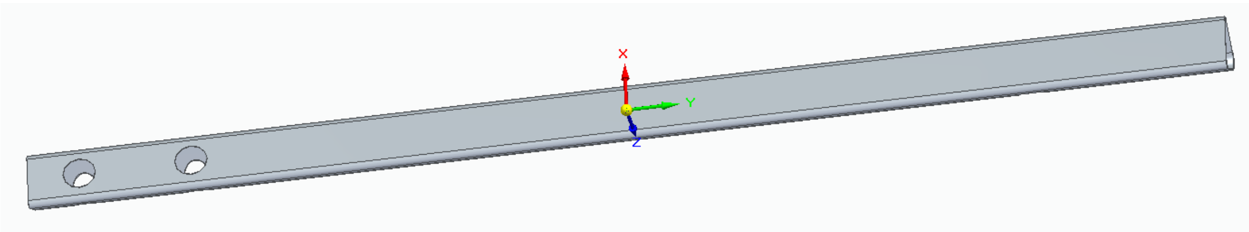


Figure 11: CAD model

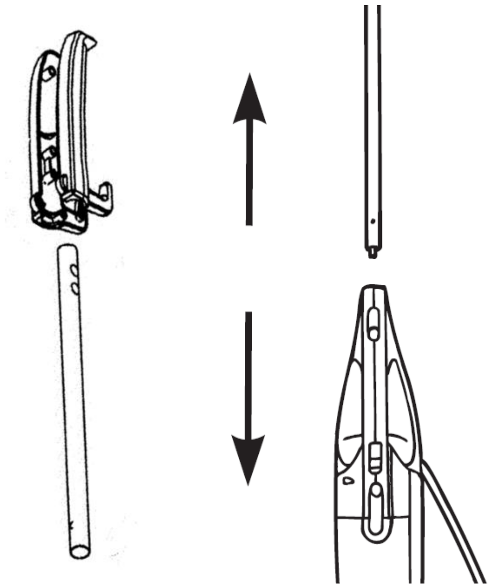


Figure 12: Assembly of the piece (Source: Dirt Devil)

11. Manufacturing Cost Analysis of the Existing Product

To know the approximate cost of producing the piece under study, the Apriori software is used. This software allows, using the CAD file of the piece and inserting parameters corresponding to the material, manufacturing process, volume of production, etc. know the final cost of the piece, as well as the cost of each of the processes carried out, the material and the machines.

To carry out the analysis, it has been assumed that the steel used has been the AISI 301. This type of steel has been chosen because it has a low cost and good properties such as resistance to corrosion and high strength. In addition, this material is typically used in the manufacture of electrical appliances, so, as there is no information on the exact type of steel used by the company, the material used should be similar to, or equal to, the AISI 301. In addition, as the information on the volume of production is confidential, it is difficult to estimate accurately the number of products manufactured throughout the year. To carry out the estimation, the position in which it is found in the sales ranking of the Amazon digital sales platform has been used, thanks to this data it is possible to know an approximation of the sales in this platform and extrapolating to the different sales platforms (the product is also sold in other major platforms such as Walmart, The Home Depot, the manufacturer's own website and physical stores), a coherent estimation can be achieved. With the use of an Amazon sales estimator, estimated sales of approximately 3,500 units per month and about 42,000 units per year are obtained. A factor of 3.5 has been used to extrapolate the units sold in other platforms, so the final estimated sales value of this product is approximately 150,000 units per year.

The other parameter that has been estimated has been the time during which this product is going to be manufactured. Despite the competition in the sector of the vacuum cleaners, the technological evolution in this sector is slow and it is difficult to observe drastic changes, reason why it is expected that the models last in the market during enough years. Due to this, a production of the model has been assumed for 8 years, which allows a great amortization of the machines and molds used in the manufacturing process of the product. Although it is possible that the model under study lasts in the market less than 8 years, it is very typical in the sector to update the models with small improvements, keeping in many cases the external appearance and most of the pieces used.

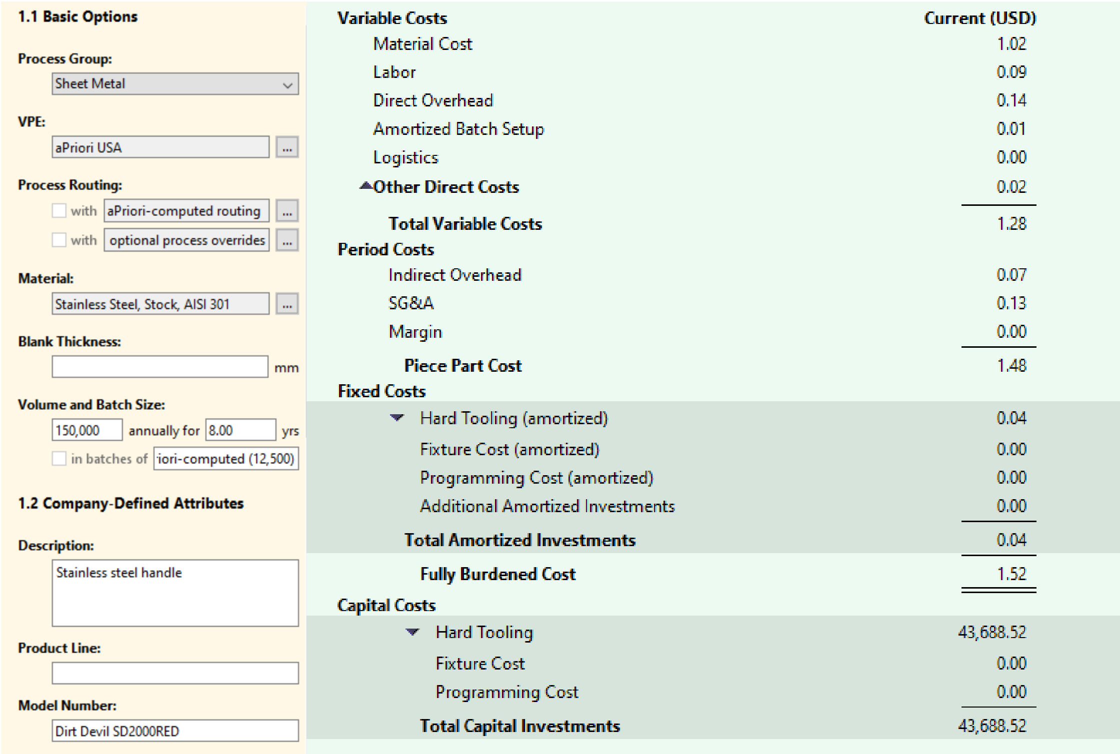


Figure 13: Cost summary of the original piece

As can be seen in the breakdown of expenses, the price of manufacture of each piece is $1.52, of which more than 65%, $1.02, is equivalent to the price of the material, in this case stainless steel. Other of the most noteworthy expenses are labor, $0.09 per piece, direct and indirect overhead, $0.14 and $0.07 respectively, and the SG&A expenses (Selling, General & Administrative Expense). Direct overheads are expenses directly associated with production of the products, such as electricity or maintenance, while indirect overheads expenses are other costs such as office supplies or telephone bills. SG&A expenses include the advertising, payroll costs, commissions and more expenses related to sales and administration. In addition to the manufacturing price of each product, a large initial investment in machinery and tools is needed. Although the initial investment required is more than $ 43,000, since the product has a long life in the market, 8 years, this investment is amortized and the cost per piece of said machinery is only $0.04.

Although the final price of the piece is only $1.52, this is approximately 15% of the manufacturing price of the final product, as previously estimated. Since this piece is not one of the main ones, and also does not perform any complex function, this manufacturing price is quite high, being this one of the reasons why a study of this piece will be carried out to try to reduce these costs and, as much as possible, add functional addictions that improve the product.

12. New Concepts

After carrying out different analyzes on the manufacture and assembly of the product, the part of the product in which a significant improvement can be carried out is the stainless-steel handle. In addition, the analysis of functionality indicated that customers required some changes in that part, so the feasibility of a change of design of the piece that allows, if possible, an improvement in manufacturing costs and, at the same time, add new features that please customers.

Considering the results of these analyzes, three ideas are proposed that improve some of the previously mentioned aspects and the viability of their implementation will be studied. For this, the pros and cons of each idea will be analyzed and a comparison of the ideas will be made through a Pugh matrix to choose which design or designs, if it were possible to implement more than one idea at the same time, is better.

- Extendable handle

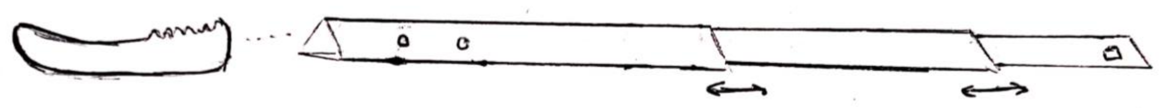


Figure 14: Sketch of the extendable handle

The main requirements that customers requested were to reduce size and weight, to make it portable and easy to store, and in addition, to improve the ergonomics of the product. A usual criticism was that the height of the vacuum could not be regulated, so it could be annoying according to the height of the person who uses it and could cause muscle and back pain. With the incorporation of an extendable handle, this problem is eliminated since the person can adjust the height of the handle itself, increasing comfort and avoiding injuries, in turn, the incorporation of an extendable handle allows to store the vacuum without the need to dissemble the parts, avoiding breaks and improving the durability of the product. In addition, being able to fold the handle, it is much easier to transport from one room to another, thus improving its portability.

To carry out this idea, a mechanism similar to that used in luggage handles or car antennas is used, that is, several concentric tubes that are inserted one inside the other and that allow them to unfold and adjust them to the customer's need. Apart from the advantages described above, this product will have a higher cost than the original part, since several tubes of different sizes and an assembly process are needed, in addition to pieces to join the different tubes. The manufacturing cost will not be much higher, since the amount of material will be similar although more processes will be needed to manufacture them and different machines for each tube size, however, the cost increase will come in the assembly process since the original part does not need any type of union.

- Change handle material

The product is made mostly of ABS plastic, by injection molding, however the handle is almost the only piece that has been manufactured in another material. It is obvious that the properties of stainless steel are better than plastic, however, its price is also higher, so finding an alternative to this material could reduce the final cost of the product, in addition, if the piece can be manufactured with ABS, like the rest of the product, the cost reduction would be greater since it would not need an investment in new machines and would allow a purchase of greater raw material, reducing the cost of it. For this material or any other material to be a valid alternative, it needs to have mechanical properties that support the task of which it is designed.

It is difficult to know the specific properties that the handle needs to have, but after evaluating its use it seems that mechanical properties as high as those of stainless steel are not necessary. The technical characteristics of this material are presented below. Furthermore, if the design of the handle is changed, increasing the thickness of the walls, better mechanical characteristics can be achieved, so that, although the piece is made of another less resistant material, enough characteristics can be achieved. Some of the alternatives that are proposed for the new material are ABS plastic and aluminum alloy.

General properties

Density	1.01e3	-	1.21e3	kg/m^3
Price	* 2.26	-	2.49	EUR/kg

Mechanical properties

Young's modulus	1.1	-	2.9	GPa
Yield strength (elastic limit)	18.5	-	51	MPa
Tensile strength	27.6	-	55.2	MPa
Elongation	1.5	-	100	% strain
Hardness - Vickers	5.6	-	15.3	HV
Fatigue strength at 10^7 cycles	11	-	22.1	MPa
Fracture toughness	1.19	-	4.29	MPa.m^0.5

General properties

Density	2.5e3	-	2.9e3	kg/m^3
Price	* 1.88	-	2.06	EUR/kg
Date first used	1916			

Mechanical properties

Young's modulus	68	-	80	GPa
Shear modulus	25	-	28	GPa
Bulk modulus	64	-	70	GPa
Poisson's ratio	0.32	-	0.36	
Yield strength (elastic limit)	95	-	610	MPa
Tensile strength	180	-	620	MPa
Compressive strength	95	-	610	MPa
Elongation	1	-	20	% strain
Hardness - Vickers	60	-	160	HV
Fatigue strength at 10^7 cycles	57	-	210	MPa
Fracture toughness	21	-	35	MPa.m^0.5
Mechanical loss coefficient (tan delta)	1e-4	-	0.001	

Figure 15: ABS plastic properties vs Aluminum

Economic attributes

Relative tooling cost	medium			
Relative equipment cost	medium			
Labor intensity	low			
Economic batch size (units)	1e3	-	1e8	

Cost modeling

Relative cost index (per unit)	11	-	24.6	
Parameters: Material Cost = 7.96EUR/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate =				
Capital cost	6.53e3	-	6.53e4	EUR
Material utilization fraction	0.7	-	0.8	
Production rate (units)	200	-	5e3	/hr
Tooling cost	131	-	1.31e4	EUR
Tool life (units)	1e4	-	1e6	

Economic attributes

Relative tooling cost	very high			
Relative equipment cost	high			
Labor intensity	low			
Economic batch size (units)	1e4	-	1e6	

Cost modeling

Relative cost index (per unit)	* 14.5	-	39.6	
Parameters: Material Cost = 7.96EUR/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate =				
Capital cost	* 2.61e4	-	5.88e5	EUR
Material utilization fraction	* 0.6	-	0.9	
Production rate (units)	* 60	-	1e3	/hr
Tooling cost	* 2.61e3	-	2.61e4	EUR
Tool life (units)	* 1e4	-	1e6	

Figure 16: Sheet Stamping Cost vs Injection Molding

As can be seen in the tables, the properties of ABS plastic are considerably lower than those of stainless steel, while aluminum lies between the two. The price per kilogram of both alternatives are very similar and the manufacturing processes of each material, the sheet stamping, corresponding to aluminum, being a little cheaper than the plastic injection molding. The ABS has as a point in favor that the rest of the parts of the product is made with this material, so it does not need a new investment in machinery and the purchase price will be lower. On the other hand, if the machinery used to manufacture the stainless-steel handle can be used for aluminum, a new investment will not be necessary either.

- Combine the handle with the grip

Figure 17: Sketch handle with the grip

Assuming that the handle was made of ABS plastic, it is necessary that both parts are made of the same material, the handle could be combined with the grip, creating a single piece that would be made by injection molding. Currently, the grip is composed of two pieces of ABS plastic, which are joined together and with the handle through two holes in the handle and with the use of two hooks located in one of the sides of the grid, without any additional element. The product is shipped without the handle and grip assembled, so the union of both would not mean a saving in the cost of assembly, in addition, this union would also mean a larger packaging size, so it would mean more transport and storage costs. Although only one mold would be needed, the costs of creating new molds and the price increases in both transportation and storage make this option unviable or at least, less advantageous than the other options because the final savings will be minimal or even, the costs of the changes may be greater than the current manufacturing price.

Customer requirements	**Weight**	**Design 1**	**Design 2**	**Design 3**
Variable height	9	+1	0	0
Lightweight	9	-1	+1	0
Possibility of disassembly	7	+1	0	-1
Easy to store	8	+1	0	-1
Portability	7	+1	0	0
Durability	6	+1	-1	0
Cost	10	-1	+1	0
Scores		18	13	-15

Table 11: PUGH Matrix

As indicated by the PUGH matrix, in which options are assigned scores relative to a criterion, the first two ideas, the extendable handle and the change of material, are the best alternatives to the current design. Both ideas are complementary, since the price increase that involves the creation of an extendable handle, since it needs more material and more manufacturing processes, is balanced with the reduction of cost when using a cheaper material such as ABS or aluminum, for what is achieved an improvement of functionality and at the same time, a reduction of product cost. Next, the design of the product will be carried out with a design software and later, a 3D printer will be used to materialize the improved product. As the 3D printers use a PLA plastic, a material like ABS although a little stronger, it will be possible to prove if this type of material holds well the task for which it is designed.

General properties				
Density	1.21e3	-	1.25e3	kg/m^3
Price	* 1.75	-	2.11	EUR/kg
Date first used	1993			
Mechanical properties				
Young's modulus	3.45	-	3.83	GPa
Shear modulus	* 1.23	-	1.37	GPa
Bulk modulus	* 5.7	-	6.3	GPa
Poisson's ratio	* 0.38	-	0.4	
Yield strength (elastic limit)	48	-	60	MPa
Tensile strength	48	-	60	MPa
Compressive strength	48	-	60	MPa
Elongation	5	-	7	% strain
Hardness - Vickers	* 14	-	18	HV
Fatigue strength at 10^7 cycles	* 14	-	18	MPa
Fracture toughness	* 0.7	-	1.1	MPa.m^0.5
Mechanical loss coefficient (tan delta)	0.02	-	0.1	

Figure 18: PLA properties

13. CAD modeling of the New Product

After carrying out all the previous analyzes, we have chosen to combine the improvement of functionality by creating an extendable handle and, in addition, changing the material with which it was originally manufactured, in order to save costs. Two different designs of the same piece have been made, one designed to be created with aluminum and another, with wider walls, to be manufactured in plastic. This increase in thickness allows to compensate the mechanical properties that are lost when changing the material to plastic, also allows the creation of a mold less complex and therefore, easier to design and manufacture.

Subsequent cost and experimental analysis, a prototype will be made with a 3d printer, will allow us to choose which of the two materials is more suitable in terms of quality, strength and price.

To create an extendable handle, two different pieces have been created that are inserted one inside the other. The shape of the original piece has been reproduced on the exterior piece, including the lower hole it has to be inserted in the hand vacuum. In addition, several holes have been created that will allow the interior piece to be fixed at different heights. The inner piece, with the same shape but smaller size, in order to be inserted in the other, has a cavity where a button is housed that serves to fix said piece to the outer piece, in addition, it has the holes where the grip is inserted. The mechanism to change the height of the handle consists of a button inserted in the cavity of the inner piece that thanks to a spring allows to be inserted in the holes of the outer piece and fix both parts. To change the height again, it is only necessary to push the button inwards and move the inner part to the next hole.

Thanks to the extendable handle, a maximum length of 465 mm and a length when folded of 350 mm are achieved, in addition, there are to two other intermediate positions that allow a length of 430 mm and 447.5 mm.

13.1. Inner piece

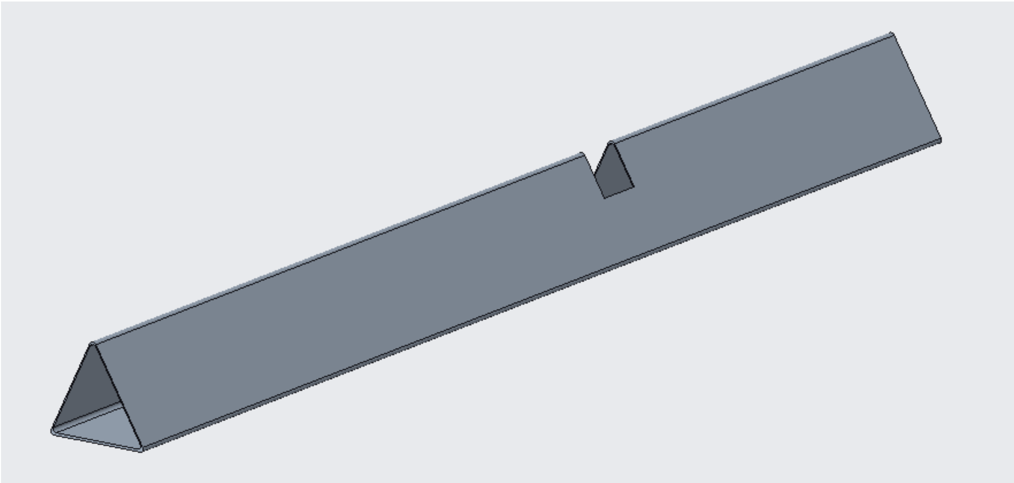


Figure 19: Inner piece, top view

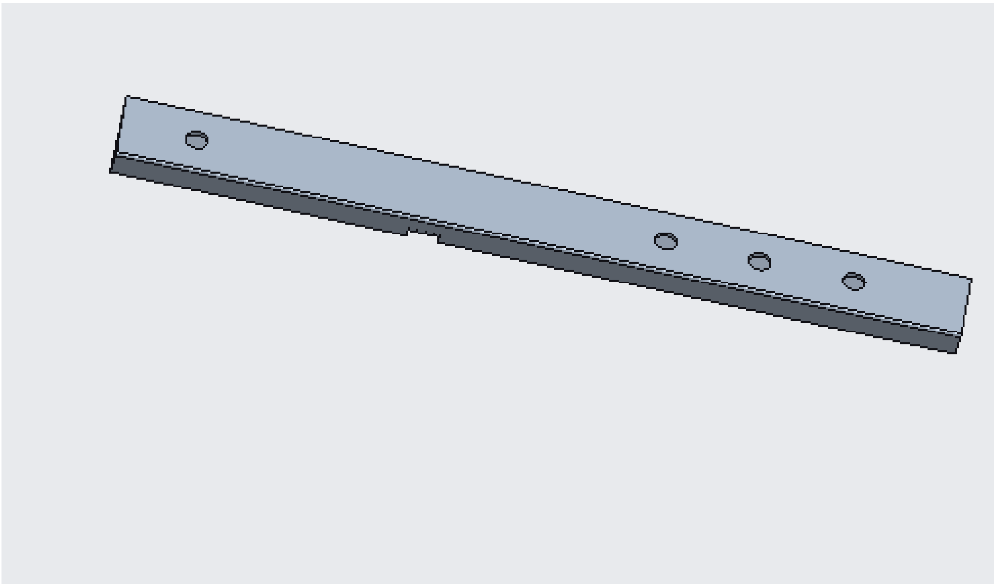


Figure 20: Inner piece, bottom view

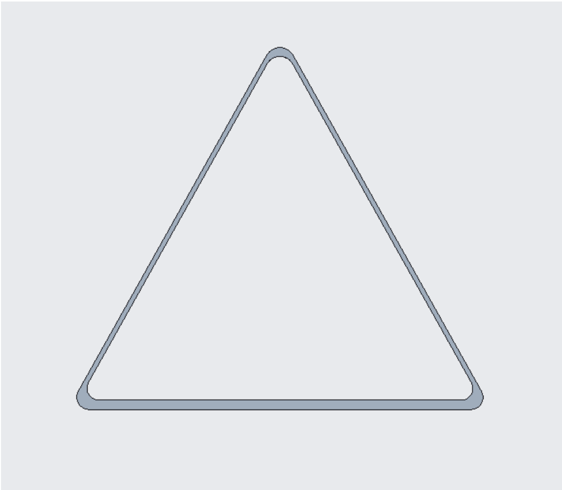


Figure 21: Inner piece, frontal view, design for Aluminum

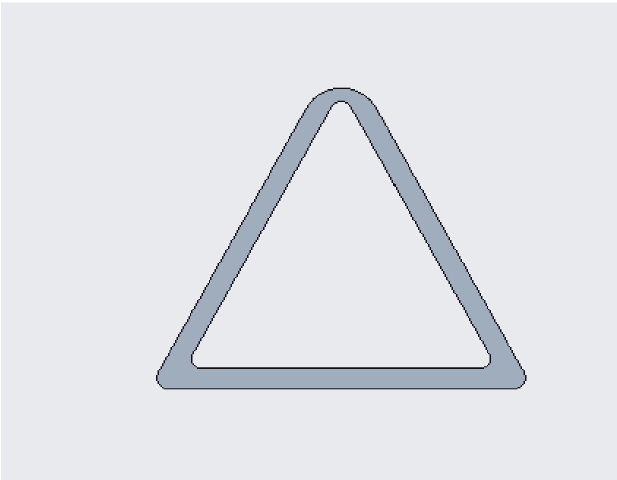


Figure 22: Inner piece, frontal view, design for ABS plastic

13.2. Outer piece

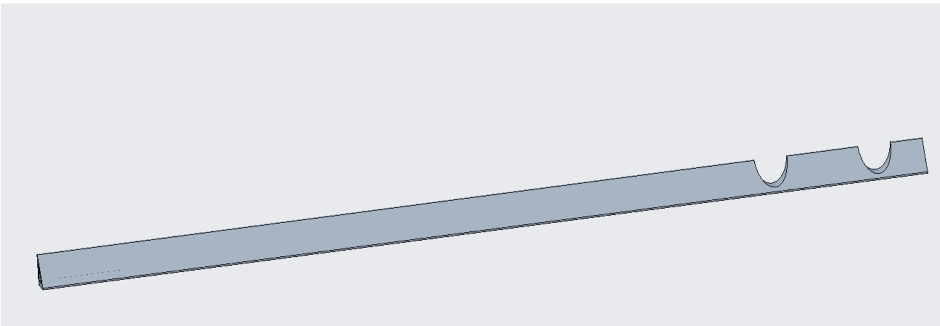


Figure 23: Outer piece, lateral view

Figure 24: Outer piece, bottom view

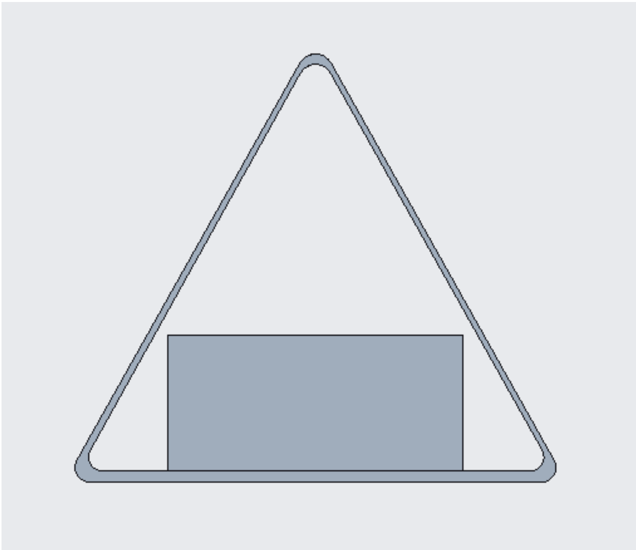


Figure 25: Outer piece, frontal view, design for Aluminum

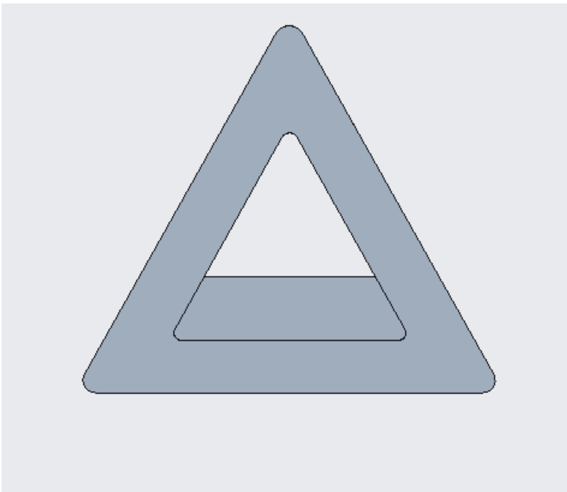


Figure 26: Outer piece, frontal view, design for ABS plastic

13.3. Button

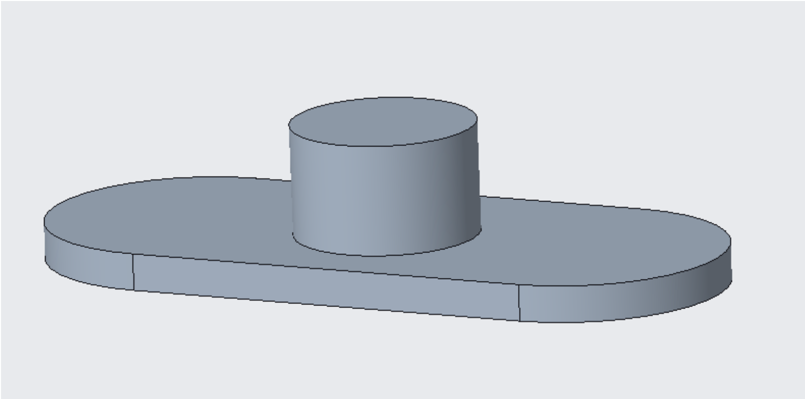


Figure 27: Bottom

13.4. Assembly

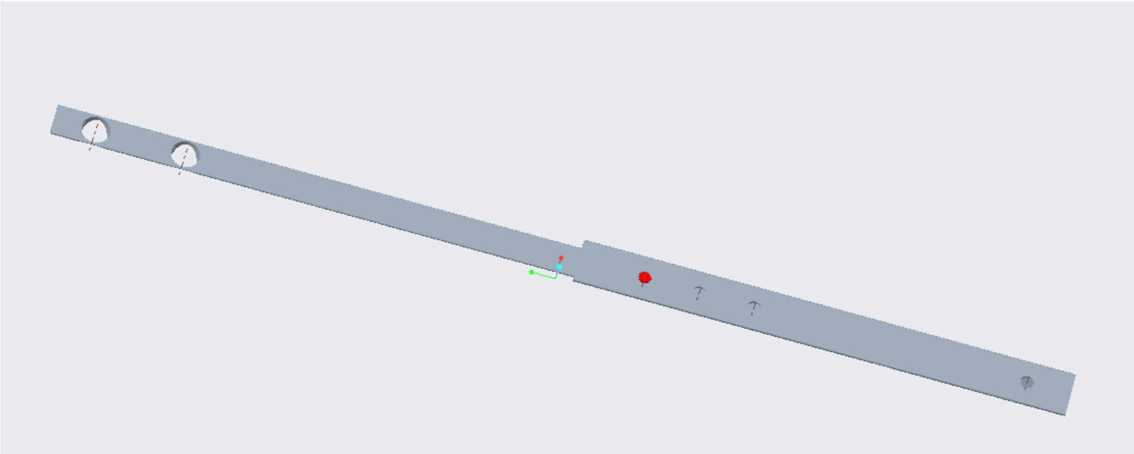


Figure 28: Handle at its maximum extension

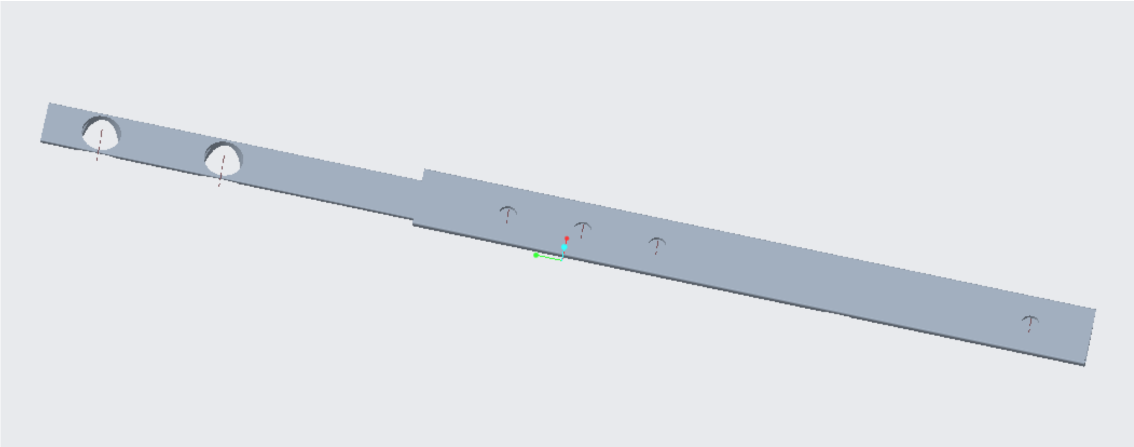


Figure 29: Folded handle

14. 1st Physical prototype of the redesigned component

After having made the design of the improved piece, a physical prototype is created to check the functionality and the changes brought by the new improvements. This prototype will be made thanks to 3d printing, which also allows us to check if the plastic endures the task for which it is designed. For the manufacture of this prototype has been used a 3d printer Lulzbot TAZ 6, whose technical specifications are shown below, and the Cura software.

Key Technical Specifications

- Tool Head: TAZ Single Extruder Tool Head v2.1, 0.50mm nozzle
- Layer Resolution: 0.05 mm - 0.4 mm (0.002 in - 0.02 in)
- Max Hot End Temperature: 290°C
- Print Surface: Borosilicate Glass/PEI
- Max Print Surface Temperature: 120°C
- Leveling: Automatic Z-Axis Compensation
- Certifications: FCC, CE, WEEE, OSHWA, FSF-RYF

Figure 30: Lulzbot Taz 6 printer

Print Volume Dimensions

280 mm x 280 mm x 250 mm

(11.02" x 11.02" x 9.80")

Print Volume

19,600 cm^3 (1,185 in^3)

To make the impression, the file of the piece designed in "stl" format is inserted in the Cura software, which slices the user’s model file into layers and generates a printer-specific g-code. To be able to carry out 3d printing, it has been necessary to increase the thickness of the walls and divide the piece into several parts, due to the limitations of the printer. Approximately 52g of PLA have been used and the printing lasted more than 5h.

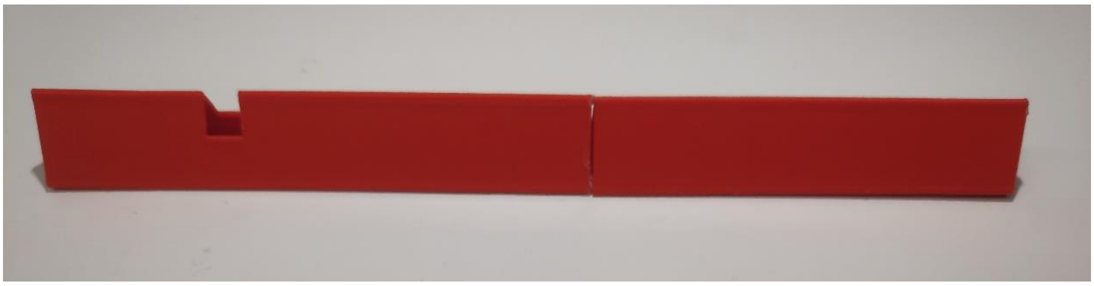


Figure 31: Inner piece, top view

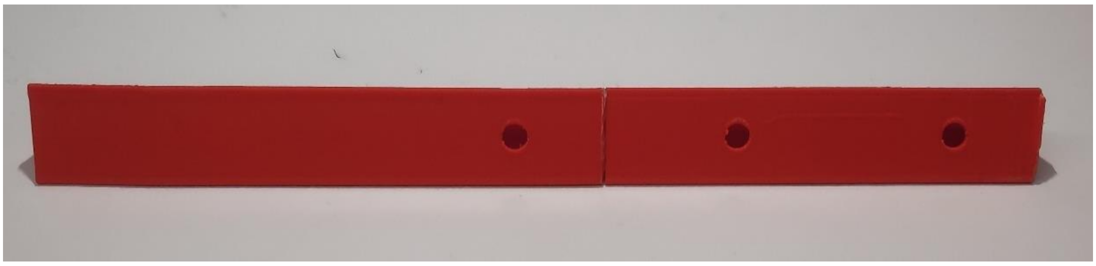


Figure 32: Inner piece, bottom view

Figure 33: Outer piece, lateral view, with the spring and the button

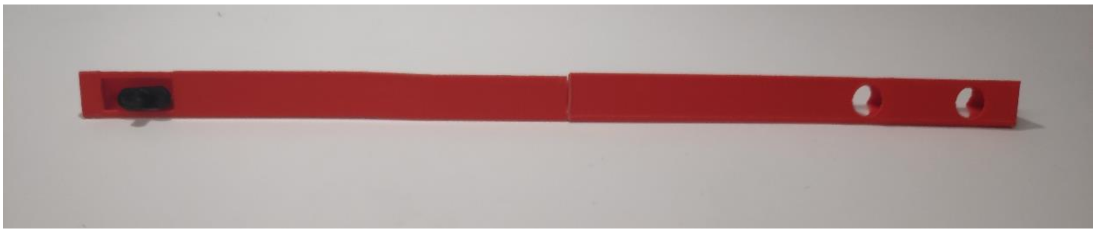


Figure 34: Complete piece, lateral view

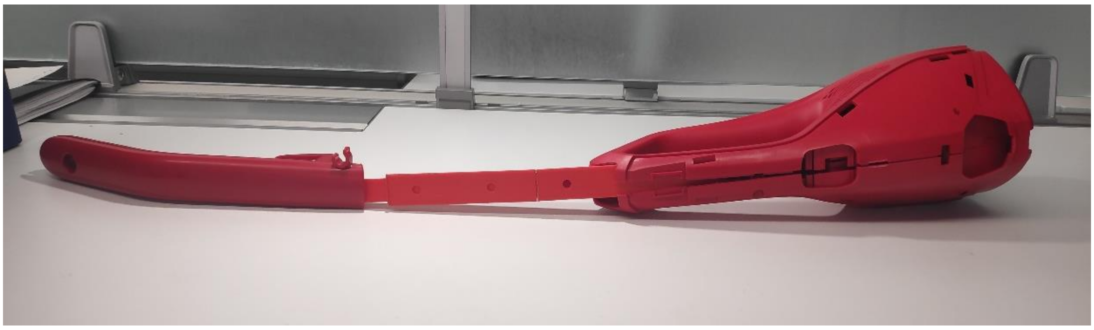


Figure 35: Handle with the grip and the hand-vacuum case

After collecting and assembling the pieces, it can be observed how the extendable handle works perfectly and everything fits perfectly with the rest of the original pieces. However, despite the increased thickness of the walls of the handle, the mechanical properties that gives the plastic, despite being PLA its properties are similar to ABS, they are not enough to get a good performance and a more resistant material, such as aluminum, will be needed.

15. Design of experiment method

After making the changes in our product and implementing the new improvements, we want to carry out a study that shows us if the changes made affect the satisfaction of the clients, and which of the changes affects the most. To carry out this analysis, different combinations of the vacuum cleaners, with and without the changes implemented, will be given to different people to test them for a short period of time and give their valuation and the degree of satisfaction with said product. In order to achieve the highest possible precision in the study, people of different sizes, ages and sexes will be sought to see if the improvements adapt well to all types of people.

The variables that will have the different combinations of vacuum cleaners will be the type of material, stainless steel or aluminum, and whether it has an extendable handle or not. With this, we can compare the old product with the new, and see if the changes affect the company's goal of achieving greater customer satisfaction that results in a greater number of sales.

Factors	**Levels**	
	Low (-)	High (+)
Material	Stainless steel	Aluminum
Extendable handle	No	Yes

Table 12: Factors

To carry out this study a DOE (Design of Experiment) is used, this method consists of, through some samples, determining how, through the average of the output, which one or ones of the inputs and the correlations between them affect more to the output and which can be considered insignificant. By means of a statistical analysis the effect of each variable or correlation in the output is obtained, and it can be obtained according to the chosen level of significance, which variables are significant or not.

To take this analysis to real life with our product, it will be necessary to manufacture the four combinations, and the products will be given to people for a short period to try and evaluate them. A good number of individuals to perform the test can be between 20 and 30 people, which allows us to group people of different sizes, ages and sex that encompasses the entire population for which our product is designed. After testing each product, each person will conduct a satisfaction survey for each of the possible combinations, all of these data are stored and organized and the DOE analysis is performed.

Below is an example of how this experiment is performed, the statistical calculations and results obtained. Although in this example only three trials have been used, the results obtained should be similar to those obtained in reality.

Combination	**Material**	**Extendable handle**	**Customer satisfaction (1-10)**			
			Trial 1	Trial 2	Trial 3	Average
1	+	+	10	10	9	9.67
2	-	-	5.5	6	5.5	5.67
3	+	-	6.5	7	5	6.17
4	-	+	9.5	10	9	9.5

Table 13: Design Matrix

Standard deviations	**Variances**	**Average**	**Average of std**	**Average of variance**	**2-sigma significance**
0.47	0,22	7,75	0,49	0.24	0.98
0,24	0,06				
0.85	0.72				
0,41	0,17				

Table 14: Statistical measures

Test	**x1**	**x2**	**x12**	**Average**
1	1	1	1	9.67
2	-1	-1	1	5.67
3	1	-1	-1	6.17
4	-1	1	-1	9.5

Table 15: Calculation matrix

Effects values:

- $E_1 = 0.5\ [(1*9.67) + (-1*5.67) + (1*6.17) + (-1*9.5)] = 0.33$
- $E_2 = 0.5\ [(1*9.67) + (-1*5.67) + (-1*6.17) + (1*9.5)] = 3.67$
- $E_{12} = 0.5\ [(1*9.67) + (1*5.67) + (-1*6.17) + (-1*9.5)] = -0.17$

Rank	**1**	**2**	**3**
Effect value	3,67	0.33	-0.17
Probability	83,33	50,00	16,67
Standard Dev.	0,97	0,00	-0,97
Effect	E2	E1	E12

Table 16: Effect values

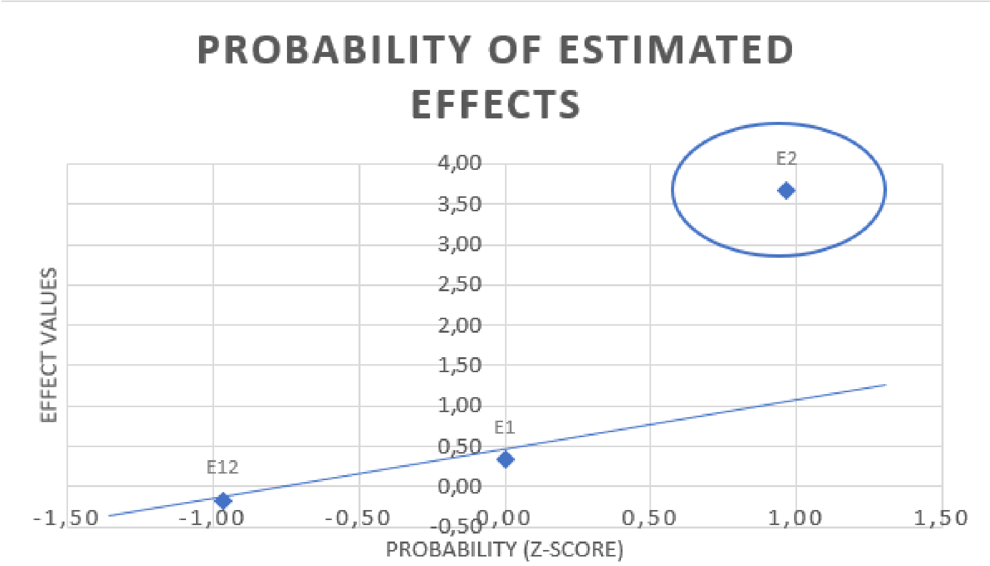


Figure 36: Probability of Estimated Effects

The 2-sigma statistically significant effects method, E2>0.98, and the graphically significant effects method shown that only the variable E2 is significant, so the predicting equation of the output is:

$$\hat{S} = \bar{S} + \frac{E_1}{2} * x_1 + \frac{E_2}{2} * x_2 + \frac{E_{12}}{2} * x_{12}$$

$$\hat{S} = \bar{S} + \frac{E_2}{2} * x_2 = 7.38 + \frac{3.67}{2} * x_2$$

This analysis shows that the only variable that is significant in customer satisfaction is the incorporation of an extendable handle, while both the material and the interaction between both variables is negligible. If these results were obtained in a real experiment they would show that the direction of improvement of our product is the correct one, since our improvement of the extendable handle is the one that contributes functionality, while the change of material is only due to the reduction of cost of manufacture that allows the use of aluminum.

16. Comparison between the original product and the improved version

The improvement of this product has focused on two main aspects, add functionality to the original product and lower manufacturing costs. To improve the functionality of the product an extendable handle has been created, which allows to adjust the height of the handle according to the person who uses it, besides, it allows a smaller size when it is folded which facilitates the storage without the need to disassemble the pieces. With the incorporation of this handle has achieved a maximum length of 465 mm, which is an increase in 25 mm from the original design.

Figure 37: Comparison between the original product and the improved version at its maximum extension

In addition to this position, the handle allows 2 additional lengths of 430 mm and 447.5 mm, in addition to a length of folding of 350 mm that supposes a shortening of 70 mm if we compare it with the initial model.

Figure 38: Comparison between the original product and the improved version at its second position

Figure 39: Comparison between the original product and the improved version at its third position

This improvement supposes an additional functionality that allows a differentiation with the rest of the products of the competition that lack extensible handle, in addition to improving the durability, by not needing disassembly to be stored since this can suppose a wear on the pieces or even breakage if it is not done correctly. If we incorporate the improved product into our QFD matrix, we can see how our product is now ahead of the competition in most aspects and thanks to the improvements, it has been possible to increase the score in three different customer requirements.

Customer Requirements (Explicit and Implicit) / Functional Requirements	Our Product: Dirt Devil SD20000RED	Competitor #1: *Black & Decker Lite BDASL202*	Competitor #2: *BISSELL PowerSwift™*	Competitor #3: *Eureka NES210*	Competitor #4: *Hoover FH50700*	Row #
Lightweight	5	3	2	5	1	1
Great performance	2	4	5	2	0	2
Durable	4	3	4	4	4	3
Bin capacity	2	4	3	0	5	4
Conversion to a hand vacuum	5	0	0	5	0	5
Portable	5	2	2	5	1	6
Low cost	5	2	2	4	1	7
Extendable handle	5	0	0	0	0	8
Easy to store	5	2	2	4	2	9
Suitable for different surfaces	3	4	4	3	5	10

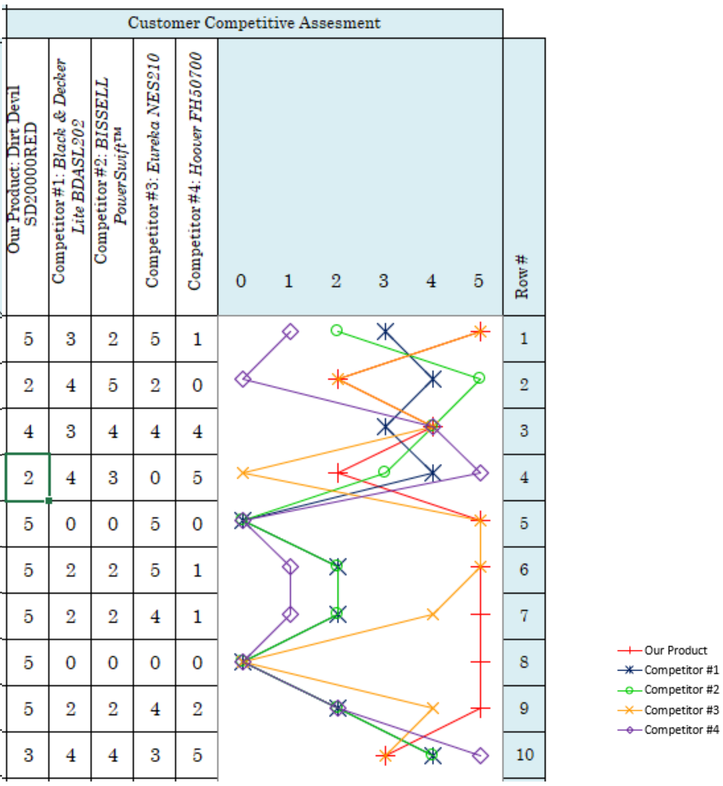
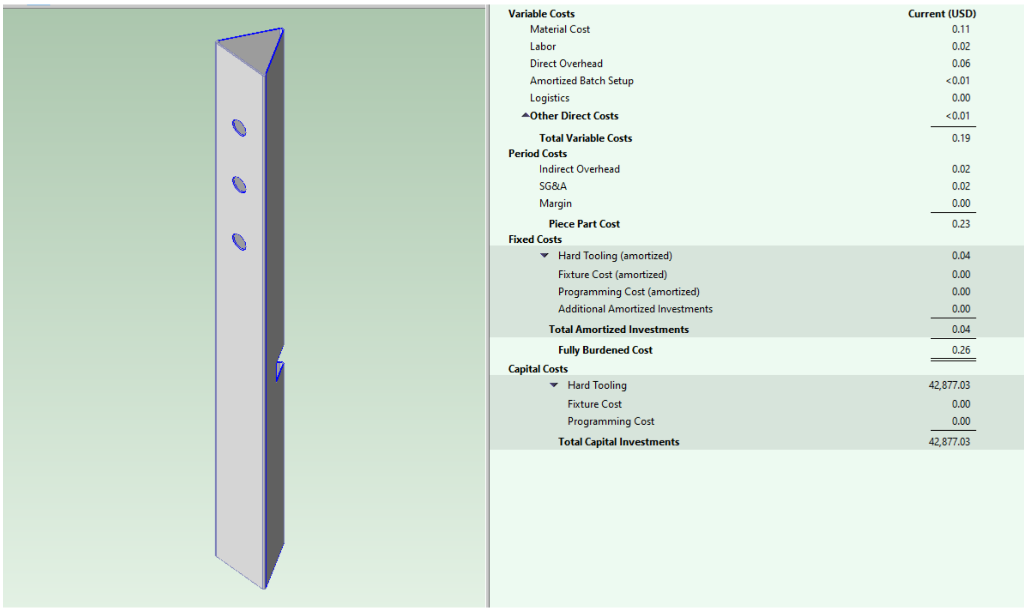


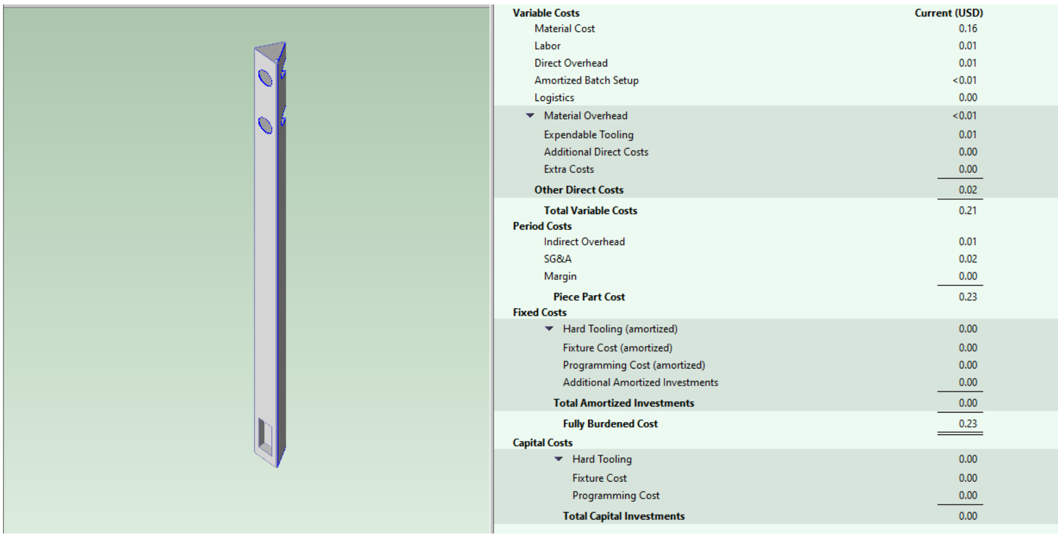
Table 17: Improved QFD matrix

However, this improvement in functionality brings with it the realization of a more complex piece that increases the number of parts to be manufactured and the amount of material used. This increase in the cost of manufacturing, has been able to balance and even reduce with respect to the original product through a change of material. If the new pieces are created in aluminum, the total cost of production of the set that would replace the original handle is $0.7, which is approximately 46% of the cost of the original piece.



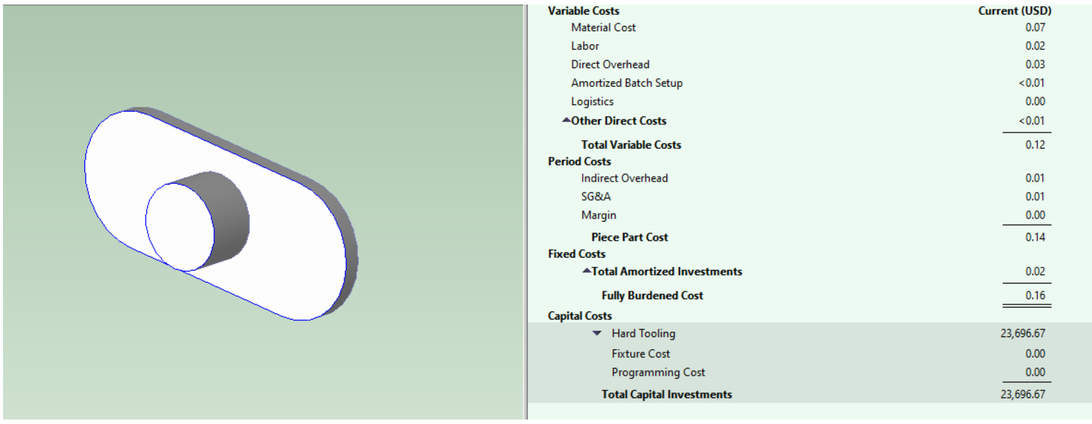
Variable Costs	Current (USD)
Material Cost	0.11
Labor	0.02
Direct Overhead	0.06
Amortized Batch Setup	<0.01
Logistics	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.19
Period Costs	
Indirect Overhead	0.02
SG&A	0.02
Margin	0.00
Piece Part Cost	0.23
Fixed Costs	
Hard Tooling (amortized)	0.04
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.04
Fully Burdened Cost	0.26
Capital Costs	
Hard Tooling	42,877.03
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	42,877.03

Figure 40: Cost summary of the outer piece



Variable Costs	Current (USD)
Material Cost	0.16
Labor	0.01
Direct Overhead	0.01
Amortized Batch Setup	<0.01
Logistics	0.00
Material Overhead	<0.01
Expendable Tooling	0.01
Additional Direct Costs	0.00
Extra Costs	0.00
Other Direct Costs	0.02
Total Variable Costs	0.21
Period Costs	
Indirect Overhead	0.01
SG&A	0.02
Margin	0.00
Piece Part Cost	0.23
Fixed Costs	
Hard Tooling (amortized)	0.00
Fixture Cost (amortized)	0.00
Programming Cost (amortized)	0.00
Additional Amortized Investments	0.00
Total Amortized Investments	0.00
Fully Burdened Cost	0.23
Capital Costs	
Hard Tooling	0.00
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	0.00

Figure 41: Cost summary of the inner piece



Variable Costs	Current (USD)
Material Cost	0.07
Labor	0.02
Direct Overhead	0.03
Amortized Batch Setup	<0.01
Logistics	0.00
Other Direct Costs	<0.01
Total Variable Costs	0.12
Period Costs	
Indirect Overhead	0.01
SG&A	0.01
Margin	0.00
Piece Part Cost	0.14
Fixed Costs	
Total Amortized Investments	0.02
Fully Burdened Cost	0.16
Capital Costs	
Hard Tooling	23,696.67
Fixture Cost	0.00
Programming Cost	0.00
Total Capital Investments	23,696.67

Figure 42: Cost summary of the button

To know the price of manufacturing of the new design with the new material, the software Apriori has been used that allows to predict the cost using the CAD file. Aluminum ANSI 5019 has been used as material, one of the cheapest in the market and with sufficient mechanical characteristics to carry out the task for which the handle is designed. For the rest of parameters such as the number of units and production time, the same estimated data was used as with the original, that is, 150,000 units per year for 8 years. To estimate the purchase price of the spring, the portal “McMaster-Carr” has been used as a reference, and an approximate price of 5 cents has been obtained, assuming a wholesale purchase and therefore a large reduction in the cost that if it is purchased individually.

Composition Properties	
Name	Aluminum, Stock, ANSI 5019
Description	Grade 5019 (old DIN 3.3261.0...
Material Type	Aluminum
Cut Code	30.11
USA Name	Aluminum, Stock, ANSI 5019
DIN Name	EN AC-AlMg5(Si)
EN Name	EN AC-51400
GB Name	ZAlMg5Si
JIS Name	AC7A
Unit Cost (USD / kg)	8.633
Cost Units	Cost per KG
Cost Per Unit	8.633

Table 18: Aluminum ANSI 5019 properties

The change of material would mean a saving per piece of $0.82, which would be equivalent to about $123,000 less per year. In addition, if we take into account that the processes to manufacture the piece in aluminum are the same as for the piece of stainless steel, except maybe some tools, the savings would be greater because it would not need a large investment in new machinery. This reduction in the cost of manufacturing allows the drop in the price of sales or on the contrary an increase in profit for the company. However, this reduction in the cost of the material also implies a reduction in the mechanical properties due to the fact that stainless steel is stronger and more resistant than aluminum. Nevertheless, since the handle does not need very demanding mechanical characteristics, this change does not mean a big difference for the consumer since the aluminum perfectly meets the minimum requirements.

Furthermore, to achieve this improvement in functionality, it is necessary to add an additional assembly process, since although the piece is sent without mounting, the button must be placed in the cavity with the spring, so the assembly time increases and therefore, also the cost of the process.

						Handling and Alingment		Insert and Secure		
Operation Number	Times Operation is Carried Out	Part Description	Part Required	Alpha (deg)	Beta (deg)	Description	Time (sec)	Description	Time (sec)	**Total Time (sec)**
1	1	Handle	Yes	360	0	Part fetch time: 0,5 Symmetry: 1 Part size:0	1,5	General placement: 0.5	0,5	2
2	1	Spring	Yes	180	0	Part fetch time:0,5 Symmetry: 0,5 Part size: 0,5	1,5	General placement: 0.5s Glue: 1 Spring: 0,4s	1,9	3,4
3	1	Button	Yes	360	180	Part fetch time:0,5 Symmetry: 1,5 Part size: 0,5	2,5	General placement: 0.5s Glue: 1	1,5	4
									Total Assembly Time	**9,4**

Table 19: Assembly time

Regarding the environmental issue, aluminum and stainless steel have similar properties and are two materials with high recycling ratios, so that a large amount of the material used for the manufacture of the products are recycled.

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 22.8	-	25.2	MJ/kg
CO2 footprint, recycling	* 1.79	-	1.98	kg/kg
Recycle fraction in current supply	35.5	-	39.3	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
A renewable resource?	✗			

Figure 43: Recycling data Stainless Steel AISI 310

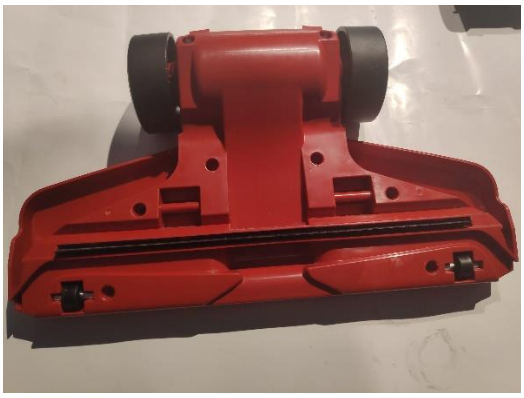
Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 25	-	27.6	MJ/kg
CO2 footprint, recycling	* 1.97	-	2.17	kg/kg
Recycle fraction in current supply	40.5	-	44.7	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
A renewable resource?	✗			

Figure 44: Recycling data Aluminum

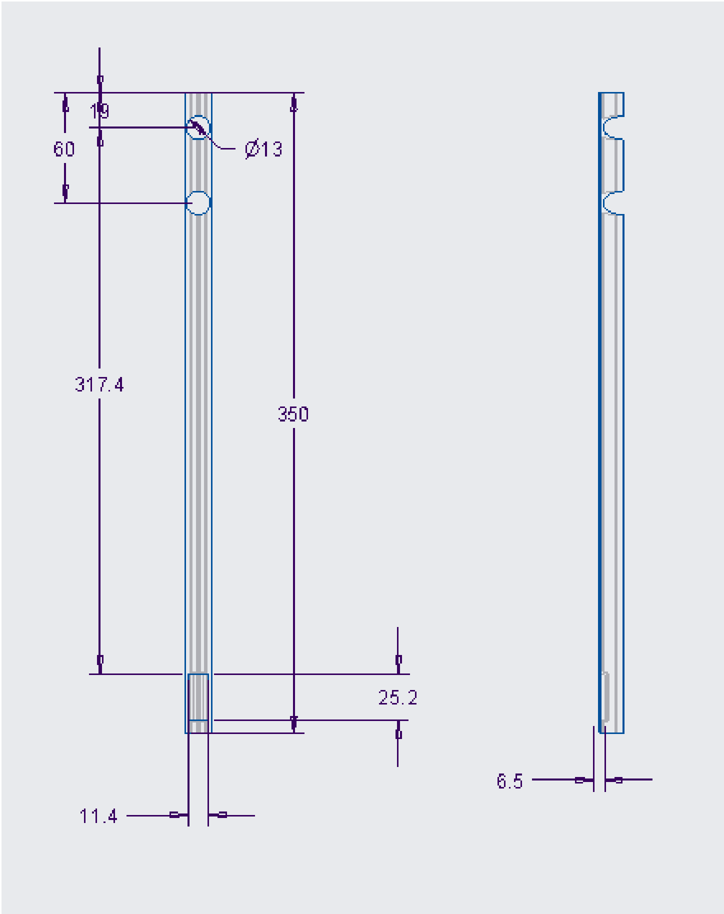
Appendices

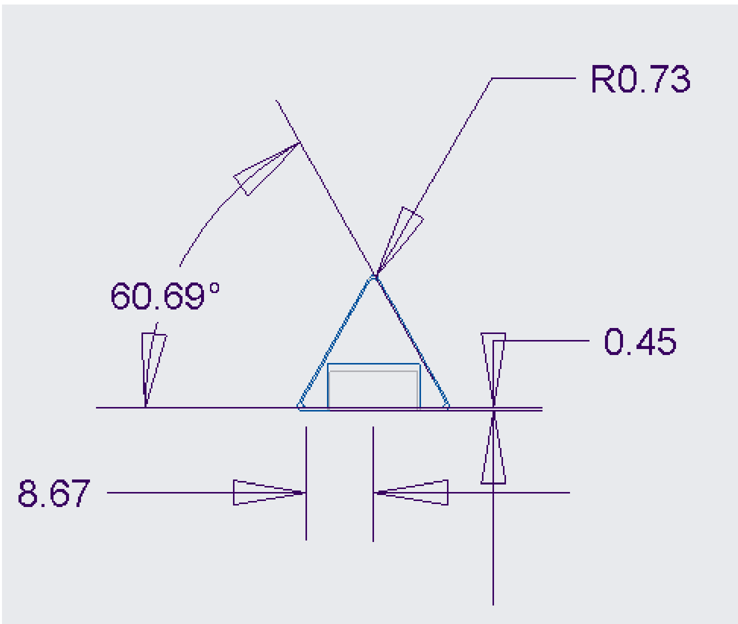
Disassembly Images



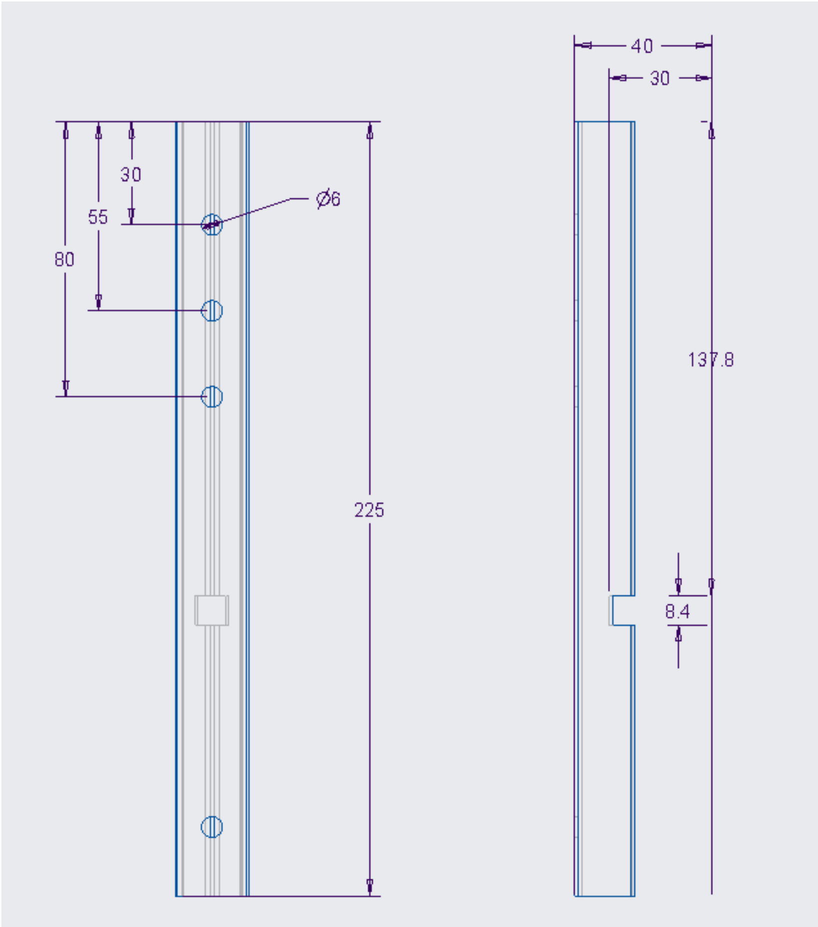
Drawings of the Improved Piece

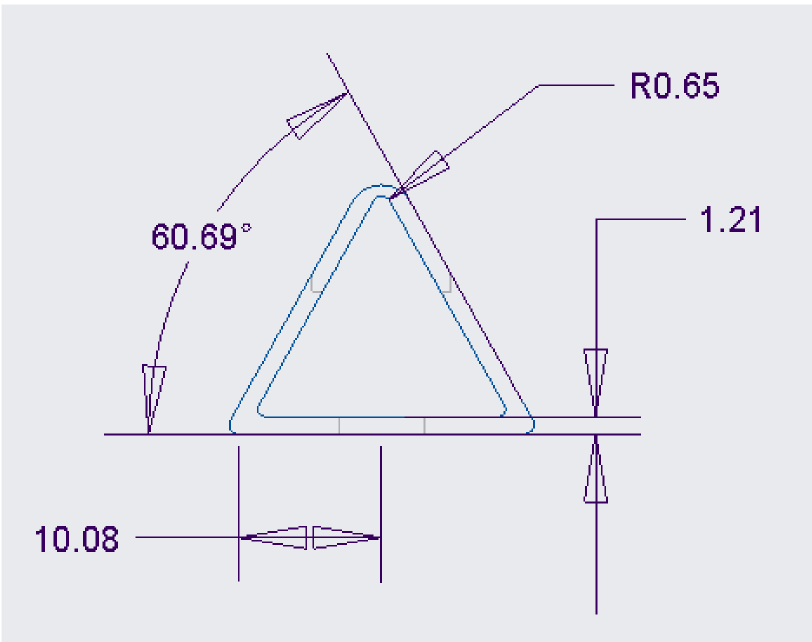
Inner Piece



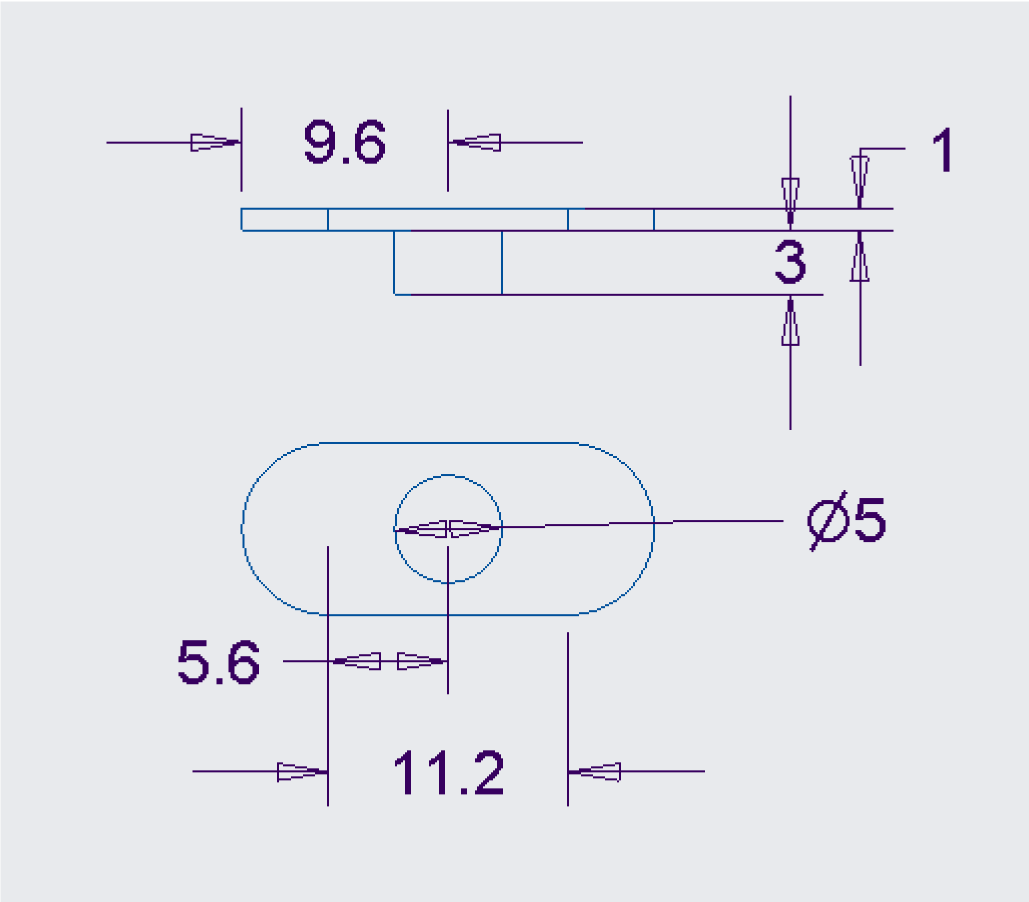


Outer Piece





Button



Technical Sheet of Materials

Stainless steel

CES 2013 EDUPACK **Stainless steel** Page 1 of 2

Description

The material

Stainless steels are alloys of iron with chromium, nickel, and - often - four of five other elements. The alloying transmutes plain carbon steel that rusts and is prone to brittleness below room temperature into a material that does neither. Indeed, most stainless steels resist corrosion in most normal environments, and they remain ductile to the lowest of temperatures.

Composition (summary)

Fe/<0.25C/16 - 30Cr/3.5 - 37Ni/<10Mn + Si,P,S (+N for 200 series)

Image

Caption

One the left: Siemens toaster in brushed austenitic stainless steel (by Porsche Design). On the right, scissors in ferritic stainless steel; it is magnetic, austenitic stainless is not.

General properties

Density	7.6e3	-	8.1e3	kg/m^3
Price	* 4.59	-	5.06	EUR/kg

Mechanical properties

Young's modulus	189	-	210	GPa
Yield strength (elastic limit)	170	-	1e3	MPa
Tensile strength	480	-	2.24e3	MPa
Elongation	5	-	70	% strain
Hardness - Vickers	130	-	570	HV
Fatigue strength at 10^7 cycles	* 175	-	753	MPa
Fracture toughness	62	-	150	MPa.m^0.5

Thermal properties

Melting point	1.37e3	-	1.45e3	°C
Maximum service temperature	750	-	820	°C
Thermal conductor or insulator?	Poor conductor			
Thermal conductivity	12	-	24	W/m.°C
Specific heat capacity	450	-	530	J/kg.°C
Thermal expansion coefficient	13	-	20	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor

Optical properties

Transparency	Opaque

Eco properties

Embodied energy, primary production	* 80.3	-	88.8	MJ/kg
CO2 footprint, primary production	* 4.73	-	5.23	kg/kg
Recycle	✓			

Supporting information

Typical uses

Railway cars, trucks, trailers, food-processing equipment, sinks, stoves, cooking utensils, cutlery, flatware, scissors and knives, architectural metalwork, laundry equipment, chemical-processing equipment, jet-engine parts, surgical tools, furnace and boiler components, oil-burner parts, petroleum-processing equipment, dairy equipment, heat-treating equipment, automotive trim. Structural uses in corrosive environments, e.g. nuclear plants, ships, offshore oil installations, underwater cables and pipes.

CES 2013 EDUPACK

Age-hardening wrought Al-alloys

Description

The material

The high-strength aluminum alloys rely on age-hardening: a sequence of heat treatment steps that causes the precipitation of a nano-scale dispersion of intermetallics that impede dislocation motion and impart strength. This can be as high as 700 MPa giving them a strength-to-weight ratio exceeding even that of the strongest steels. This record describes for the series of wrought Al alloys that rely on age-hardening requiring a solution heat treatment followed by quenching and ageing. This is recorded by adding TX to the series number, where X is a number between 0 and 8 that records the state of heat treatment. They are listed below using the IADS designations (see Technical notes for details).2000 series: Al with 2 to 6% Cu – the oldest and most widely used aerospace series.6000 series: Al with up to 1.2% Mg and 1.3% Si – medium strength extrusions and forgings.7000 series: Al with up to 8% Zn and 3% Mg – the Hercules of aluminum alloys, used for high strength aircraft structures, forgings and sheet. Certain special alloys also contain silver. So this record, like that for the non-age hardening alloys, is broad, encompassing all of these.

Composition (summary)

2000 series: Al + 2 to 6% Cu + Fe, Mn, Zn and sometimes Zr
6000 series: Al + up to 1.2%Mg + 0.25% Zn + Si, Fe and Mn
7000 series: Al + 4 to 9 % Zn + 1 to 3% Mg + Si, Fe, Cu and occasionally Zr and Ag

Image

Caption
The 2000 and 7000 series age-hardening aluminum alloys are the backbone of the aerospace industry. The 6000 series has lower strength but is more easily extruded: it is used for marine and ground transport systems.

General properties

Density	2.5e3	-	2.9e3	kg/m^3
Price	* 1.88	-	2.06	EUR/kg
Date first used	1916			

Mechanical properties

Young's modulus	68	-	80	GPa
Shear modulus	25	-	28	GPa
Bulk modulus	64	-	70	GPa
Poisson's ratio	0.32	-	0.36	
Yield strength (elastic limit)	95	-	610	MPa
Tensile strength	180	-	620	MPa
Compressive strength	95	-	610	MPa

Elongation	1	-	20	% strain
Hardness - Vickers	60	-	160	HV
Fatigue strength at 10^7 cycles	57	-	210	MPa
Fracture toughness	21	-	35	MPa.m^0.5
Mechanical loss coefficient (tan delta)	1e-4	-	0.001	

Thermal properties

Melting point	495	-	640	°C
Maximum service temperature	120	-	200	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	118	-	174	W/m.°C
Specific heat capacity	890	-	1.02e3	J/kg.°C
Thermal expansion coefficient	22	-	24	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	3.8	-	6	µohm.cm

Optical properties

Transparency	Opaque

Processability

Castability	4	-	5
Formability	3	-	4
Machinability	4	-	5
Weldability	3	-	4
Solder/brazability	2	-	3

Eco properties

Embodied energy, primary production	* 198	-	219	MJ/kg
CO2 footprint, primary production	* 12.2	-	13.4	kg/kg
Recycle	✓			

ABS Plastic

CES 2013 EDUPACK

Acrylonitrile butadiene styrene (ABS)

Description

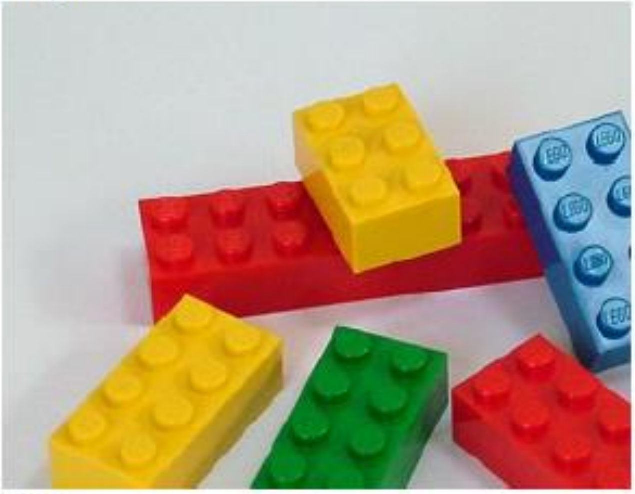
The material

ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.

Composition (summary)

Block terpolymer of acrylonitrile (15-35%), butadiene (5-30%), and styrene (40-60%).

Image



Caption

The picture says a lot: ABS allows detailed moldings, accepts color well, and is non-toxic and tough enough to survive the worst that children can do to it.

General properties

Density	1.01e3	-	1.21e3	kg/m^3
Price	* 2.26	-	2.49	EUR/kg

Mechanical properties

Young's modulus	1.1	-	2.9	GPa
Yield strength (elastic limit)	18.5	-	51	MPa
Tensile strength	27.6	-	55.2	MPa
Elongation	1.5	-	100	% strain
Hardness - Vickers	5.6	-	15.3	HV
Fatigue strength at 10^7 cycles	11	-	22.1	MPa
Fracture toughness	1.19	-	4.29	MPa.m^0.5

Thermal properties

Maximum service temperature	61.9	-	76.9	°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.188	-	0.335	W/m.°C
Specific heat capacity	1.39e3	-	1.92e3	J/kg.°C
Thermal expansion coefficient	84.6	-	234	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			

Optical properties

Transparency	Opaque			

Eco properties

Embodied energy, primary production	* 90.3	-	99.9	MJ/kg
CO2 footprint, primary production	* 3.64	-	4.03	kg/kg
Recycle	✓			
Recycle mark				

Supporting information

Typical uses

Safety helmets; camper tops; automotive instrument panels and other interior components; pipe fittings; home-security devices and housings for small appliances; communications equipment; business machines; plumbing hardware; automobile grilles; wheel covers; mirror housings; refrigerator liners; luggage shells; tote trays; mower shrouds; boat hulls; large components for recreational vehicles; weather seals; glass beading; refrigerator breaker strips; conduit; pipe for drain-waste-vent (DWV) systems.

Bibliography

Allied Market Research. (2019). Retrieved from https://www.alliedmarketresearch.com/household-vacuum-cleaners-market

Dirt Devil Company. (n.d.). *Dirt Devil*. Retrieved from https://www.dirtdevil.com/simplistik-corded-stick-vacuum/SD20000RED.html

Dirt Devil Company. (n.d.). *Dirt Devil.* Retrieved from https://images-na.ssl-images-amazon.com/images/I/A1ezda63AUL.pdf

Dirt Devil Company. (n.d.). *Dirt Devil.* Retrieved from https://images-na.ssl-images-amazon.com/images/I/61h5yl9lUTL.pdf

Erik Tempelman, H. S. (2014). *Manufacturing and Design, Understanding the Principles of How Things Are Made.* Oxford, UK: Butterworth-Heinemann.

Granta Design. (2013). CES Edupack .

LulzBot. (n.d.). Retrieved from https://www.lulzbot.com/store/printers/lulzbot-taz-6

MEEE Services. (n.d.). Retrieved from https://meee-services.com/what-is-abs-plastic-and-its-advantages/

Plastics Insight. (n.d.). Retrieved from https://www.plasticsinsight.com/resin-intelligence/resin-prices/abs-plastic/

RetLaw Industries. (n.d.). Retrieved from http://www.retlawindustries.com/Info/ABSPlastic

Statista . (n.d.). Retrieved from https://www.statista.com/outlook/16020100/109/vacuum%25C2%25A0cleaners/united-states#market-revenue

Transparency Market Research. (2018, Noviembre). Retrieved from https://www.transparencymarketresearch.com/pressrelease/household-vacuum-cleaners-market.htm

Verma, P. (2016). *Household Vacuum Cleaners Market: Global Opportunity Analysis and Industry Forecasts, 2014 - 2022.* Portland, USA.

WebFinance Inc. (n.d.). Retrieved from http://www.businessdictionary.com/