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# WEIGHT REDUCTION THROUGH AN INCREASE IN MATERIAL EFFICIENCY

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**Abstract.** *Due to environmental and commercial reasons, automakers have been looking for ways to reduce the amount of energy their cars consume throughout their life cycle. In addition, the industry has been obliged to comply with increasingly stringent and restrictive rules on vehicular emissions. Thus, there has been great focus on reducing the weight of vehicles. There are many ways to achieve the goals of weight reduction, whether by focusing on vehicles Body in White (BIW), automotive glazing, among others. This paper will describe the methodology implemented in Betim-MG plant of Fiat Chrysler Automobiles (FCA) to reduce the weight of automotive hoods. Initially it used an evaluate-and-compare procedure to identify the current status of FCA vehicles against their competition in terms of material usage efficiency. Then, a DFSS Project was launched to develop a new lightweight hood concept that could be used in future FCA LATAM based vehicles. Through the use of the DFSS methodology, a complete set of tests and functional requirements was defined. It intends to serve as a basis for designing the automotive hood in a way that can guarantee not only the weight saving but also the high quality of the product.*

**Keywords:** *weight saving, automotive hood, BIW, DFSS, material usage efficiency*

## 1. INTRODUCTION

In October 2012, the Brazilian government approved by decree a new program to encourage vehicle technology innovation. INOVAR AUTO fosters industry competitiveness by encouraging automakers to produce more efficient, safer, and technology-advanced vehicles while investing in Brazil (Façanha, 2013).

The INOVAR AUTO program encourages the relationship between universities and automakers. Within the scope of this project, it was developed a program called "PROGRAMA INOVAR FCA - UNIVERSIDADES – RESIDÊNCIA TECNOLÓGICA PARA ENGENHEIROS". It aims to stimulate innovation through a partnership with scholarship students, masters level, full time dedication, to act together with engineering professionals in the research and development of various themes of the current portfolio of FCA projects (de Souza *et al.*, 2016).

The present paper aims to present one of the projects derived from that partnership, whose main objective is to define targets for engineering measures that can help FCA develop a lightweight concept of an automotive hood. The methodology used to meet the project proposed objective includes an evaluate-&-compare strategy to identify opportunities of weight saving and a DFSS (Design for Six Sigma) approach to guide the designing processes in a way that guarantee not only the weight saving but also the high quality of the product. The paper includes a literature review on weight reduction, a description of the methodologies employed and the results of their use.

It is worth noting that none of the described methodology is exclusively binded to the hood. Thus, it is simple to make some minor adjustments to it so as to allow it to be used in any of the automotive closures.

## 2. LITERATURE REVIEW

Across the globe, the car fleet has increased over the years. Data from The International Organization of Motor Vehicle Manufactures shows that the number of vehicles in use worldwide exceeded 1.3 billion cars by 2015, or 182

vehicles per thousand inhabitants (OICA, 2017). According to WHO (2015), between 2010 and 2013 the number of registered vehicles increased by 16%.

Brazil follows a similar path. In 2012, the automobile fleet reached the approximate mark of 27 million units, from which 57% are flexible-fuel vehicles (whose engine can run on more than one fuel, mainly gasoline and ethanol), 40% are gasoline powered and only 3% still bears an engine designed to use hydrated ethanol (BRAZIL, 2013). Data trend can be seen in Fig. 1.

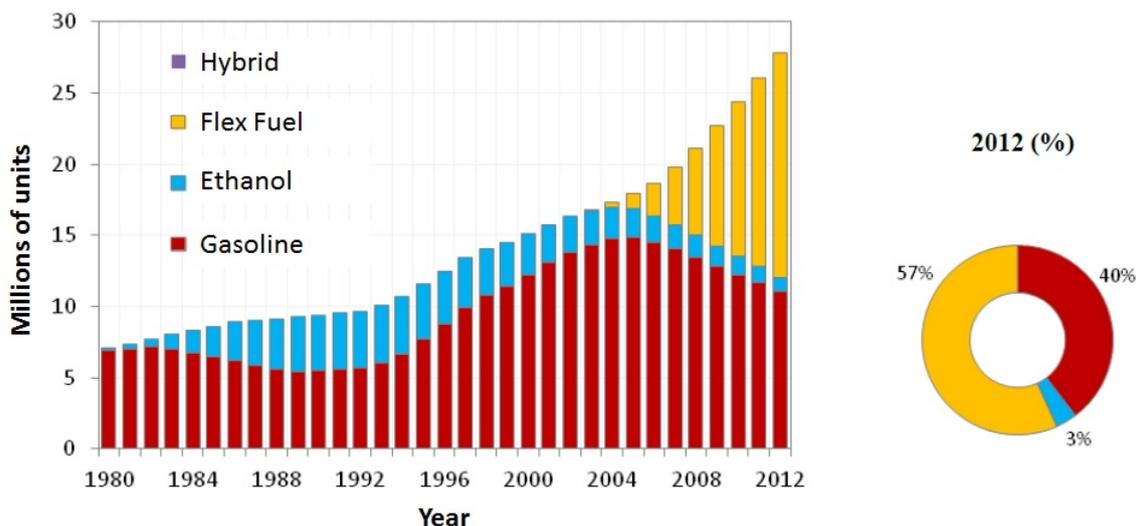


Figure 1. Evolution of the estimated car fleet by type of fuel (BRAZIL, 2013)

Such an increase in the number of vehicles in use has a number of implications. Tables 1 and 2 show the evolution of energy use in Brazil, in tonne of oil equivalent ( $10^3$  toe). It should be noted that there was an increase in energy consumption in the transport sector, especially road transport (light vehicles, light commercial vehicles and heavy vehicles), when compared to the total energy consumption of the Brazilian economy.

Table 1. Energy consumption in Brazil, from 2006 to 2010 [ $10^3$ toe].

Year	2006	2007	2008	2009	2010
Overall Consumption	202,534	215,197	226,215	220,732	241,194
Total Transport Sector	53,630	58,019	62,829	63,041	69,720
Road Transport	49,067	52,892	57,370	57,683	63,963
Railway Transport	1,040	1,115	1,149	1,125	1,135
Air Transport	2,435	2,674	2,857	2,874	3,241
Waterway Transport	1,088	1,338	1,452	1,359	1,380
% Road Transport	24%	25%	25%	26%	27%

Source: (BRAZIL, 2016)

Table 2. Energy consumption in Brazil, from 2011 to 2015 [ $10^3$ toe].

Year	2011	2012	2013	2014	2015
Overall Consumption	245,860	253,037	260,218	265,774	260,684
Total Transport Sector	73,989	79,027	83,152	86,315	84,037
Road Transport	67,896	72,721	77,007	79,945	78,267
Railway Transport	1,148	1,190	1,181	1,176	1,148
Air Transport	3,623	3,820	3,667	3,709	3,658
Waterway Transport	1,323	1,297	1,298	1,485	965
% Road Transport	28%	29%	30%	30%	30%

Source: (BRAZIL, 2016)

Of all energy consumed by the road transportation sector in Brazil, about 80% comes from non-renewable sources (derived from petroleum). In addition, the use of vehicles powered by less polluting technologies, such as electric or

hybrid, is practically inexistent (BRAZIL, 2013, 2016). The percentage distribution of the energy sources used by this sector is shown in Fig. 2.

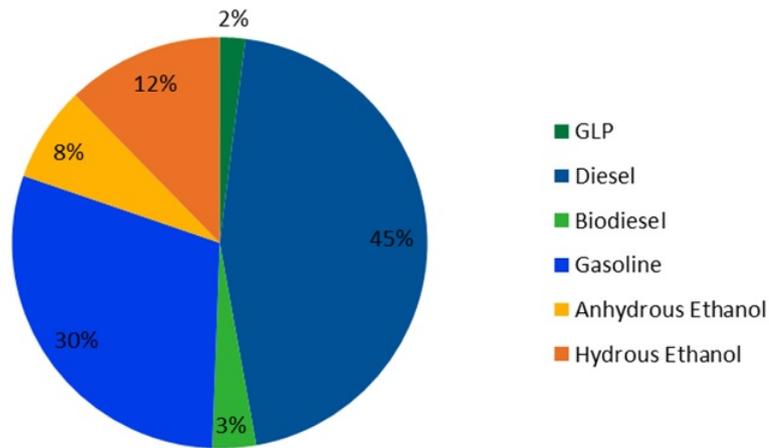


Figure 2. Energy sources for the road transport sector in Brazil (BRAZIL, 2016).

The large number of vehicles in use in Brazil combined with the use of mostly non-renewable and polluting energy sources can have harmful consequences for the environment. It is estimated that road transport sector is responsible for about 16% of man-made CO<sub>2</sub> emissions in the world (OICA, 2010). Data from the United States, which better represent the conditions of industrialized countries, shows that, in 2015, 27% of greenhouse gas emissions came from this sector (EPA, 2017). For this reason, restrictions on automotive emissions have increased over the years in order to reduce the release of greenhouse gases, such as CO<sub>2</sub>, and thereby offset the negative effect of the greater number of cars in operation.

In Brazil, the current legislation on automotive emissions is called Program for the Control of Air Pollution by Automotive Vehicles (PROCONVE, by its Portuguese acronym), which establishes emission limits for new vehicles. Acceptable emission limits have become increasingly restrictive, following the worldwide trend. The emission limits are given in Tab. 3.

Table 3. Evolution of emission limits for Otto engines in different phases of PROCONVE.

Pollutant Gas	Program Phase		
	PROCONVE L4 (2007)	PROCONVE L5 (2009)	PROCONVE L6 (2013)
Carbon Monoxide (CO)	2.0 g/km	2.0 g/km	1.3 g/km
Non-methane hydrocarbons (NMHC)	0.16 g/km	0.05 g/km	0.05 g/km
Nitrogen Oxides (NOx)	0.25 g/km	0.12 g/km	0.08 g/km
Aldehydes (HCO)	0.03 g/km	0.02 g/km	0.02 g/km
Carbon monoxide at idle	0.50% in vol.	0.50% in vol.	0.20% in vol.

Source: (CONAMA, 2002, 2009)

In addition to the emission limits for pollutant gases, INOVAR AUTO also obliged automakers to improve their corporate average vehicle efficiency for new LDVs (light duty vehicles) by about 12% from 2012 levels by October/2017 (Façanha, 2013).

Thus, this entire legal framework has led car manufacturers to develop increasingly efficient vehicles, thereby complying with the legal requirements of emission of exhaust gases and fuel economy.

To increase the efficiency of the vehicles, it is necessary to improve their fuel consumption. There are several ways to pursue this improvement, which usually fall into one of the following categories (Cheah, 2010):

1. Improvements in the engine, to increase the usable work output per unit of fuel energy input;
2. Transmission improvements, to increase the efficiency with which engine power is transmitted to driveshaft and wheels;
3. Minimizing parasitic losses, to reduce the energy wasted in accessories like cooling fan, alternator, water pump, etc.;
4. Use of alternative, more fuel-efficient powertrains, like hybrid ones;

5. Reducing the driving load, by reducing the inertial forces (weight) and resistances (aerodynamic drag, tire rolling resistance).

Weight saving falls in the last category, and it has been one of the strategies used by manufactures to reduce fuel consumption. Physically speaking, there are three forces that affect an accelerating vehicle, namely (Kühlwein, 2016):

1. Rolling resistance;
2. Inertial forces;
3. Aerodynamic drag.

It can be shown that reducing the vehicle mass has a direct impact on reducing the total tractive force required to accelerate the vehicle and, therefore, on a car's fuel consumption, once mass affects both the rolling resistances and inertial forces (Cheah, 2010).

Estimates of the practical effects of weight reduction on the consumption of a car vary. Empirical data, considering fuel consumption and the curb weight of vehicles on the US market between 2006 and 2008, show that every 100 kg of weight reduction in cars reduces fuel consumption by 0.53 L/100km. If only cars are considered (thus neglecting light commercial vehicle data), every 10% of weight reduction in a car leads to a reduction in fuel consumption of 5.6% (Cheah, 2010).

In Daimler-Benz vehicles, 100 kg of weight reduction decreases consumption by 0.2 to 0.4 L/100km (Jambor and Beyer, 1997). Cui *et al.* (2011) finds that 57 kg of weight reduction can improve fuel consumption from 0.09 to 0.21 km/L.

As a general rule, it can be assumed that 50% of the weight of a vehicle is distributed in powertrain systems (engine and transmission), while the other 50% corresponds to the body of the car (Jambor and Beyer, 1997).

The increasing use of materials lighter than steel in the engine has a weight reduction potential of about 1 to 2% in relation to the overall weight of the vehicles. If applied to the body, the potential for weight reduction increases to about 6%. As a result, automakers have focused their efforts on developing lightweight concepts of automotive bodies (Jambor and Beyer, 1997).

Automotive structures can be best lightened through innovative design strategies directed toward weight saving (e.g. thin-walled components) and by employing lightweight materials, such as aluminum and magnesium, which have the lightest density of all common structural materials (2.7 g/cm<sup>3</sup> and 1.7 g/cm<sup>3</sup>, respectively) (Hirsch and Al-Samman, 2013).

While the choice of the lightweight approach that a company will take is dependent of a myriad of factors and is essentially a decision that must be made within each company, various authors have presented insights of the pros and cons of each method.

The latest weight reduction strategies employ the concept of multi-material body, in which more than one material is used in the car structure. This optimizes the material selection process of structural components, aiming to improve performance and reduce costs. The selection strategies of the materials are diverse, and can consider factors such as capacity to withstand impacts (Cui *et al.*, 2011), ease of recycling (Sakundarini *et al.*, 2013), customer perceptions (Mayyas *et al.*, 2011) and even the total cost of the car's life cycle, considering manufacturing, use, and final disposal of the vehicle (Witik *et al.*, 2011).

### 3. METHODS

#### 3.1 WSR – Weight to Size Ratio

As already mentioned, there is currently great pressure to reduce vehicle weight to help carmakers meet their fuel consumption and energy efficiency reduction goals.

Although there are several ways to achieve this weight reduction, in all it is necessary to have a metric that allows the comparison of different projects, as well as to evaluate the performance of the developed products in comparison with its competitors in the market.

Thus, WSR (weight to size ratio) is defined as the ratio between the mass of a given component and its surface wrap area.

$$WSR = \frac{m_{part}}{A_{part}} \quad (1)$$

Where  $m_{part}$  is the mass and  $A_{part}$  is the surface wrap area of the part.

WSR allows the measurement of the material usage efficiency (also known as Weight Efficiency) in different automotive parts, and makes it possible to compare different designs. Small WSR values indicate that the part can cover a large area without being too heavy, while large values show the opposite.

Figure 3 shows schematically the concept of WSR for a hood, as well as the variables involved in its determination.

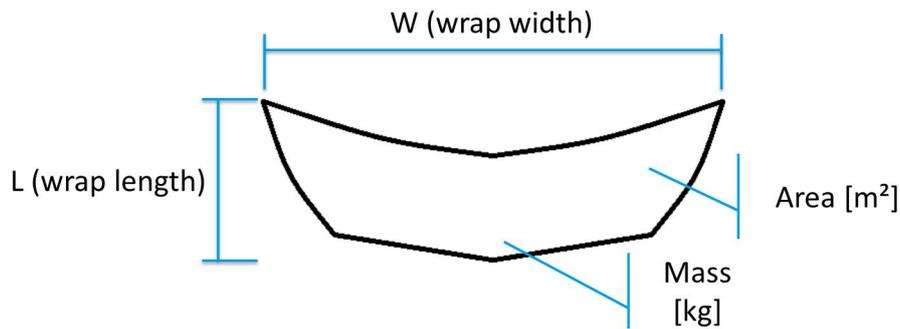


Figure 3. Schematic representation of the concept of WSR and the variables involved for an automotive hood.

### 3.2 WSR Measurement Procedure

Within the scope of this paper, it has been implemented at Betim - MG plant of Fiat Chrysler Automobiles (FCA) a methodology for the evaluation and comparison of the WSR of automotive closures (which usually encompass the doors, deck lid, liftgate and the hood), based on information obtained from A2MAC1 database ([www.a2mac1.com](http://www.a2mac1.com)). This methodology was adapted from what is currently used at the FCA US (Detroit) plant, and it was deployed to evaluate the material usage efficiency of automotive hoods.

Firstly, it has been defined a list of vehicles of interest. For each vehicle on the list, the weight and external dimensions of the hoods were collected. Photographs depicting its top, front and side views were downloaded from the system. An example of photos downloaded from A2MAC1 can be seen in Fig. 4.

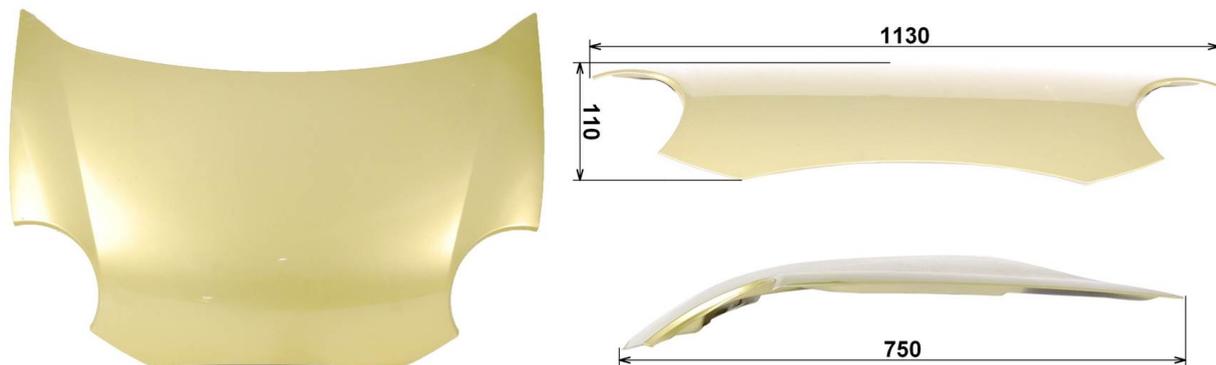


Figure 4. Chery QQ 2010 hood top and side views.

Using the open source software IMAGEJ, it was possible to measure the area of the hood. This program allows a series of measurements to be performed on images provided that an appropriate scale is defined. The steps for setting the scale are briefly shown below.

The X axis must be calibrated first, usually the width of the hood. Details regarding the procedure can be found on the program tutorial. IMAGEJ uses the inputted information to define the scale of the image (expressed in pixel / distance).

The Y axis must then be calibrated, which can be achieved by defining the image Aspect Ratio. A measured Y dimension must be compared with its known actual value. The ratio between the actual value and the value measured by the program gives the Aspect Ratio of the image, which must be informed to the software.

While setting the scale, one must be aware that the information wanted is the wrap area of the hood, and not its projected area. Thus, in situations where the hood shape is too curved, the dimensions of the envelope (width and length) must be measured beforehand so that they are given to the software as input parameters when defining the scale of the hood top view. The determination of these wrap dimensions should be done using basically the same methodology already described. One should open a picture that shows the curve to be measured, define the scale using a known dimension, and finally measure the length of the curve using IMAGEJ tools.

For the vehicle shown in Fig. 4, the length of the hood when considering its curvature was measured as 788 mm, about 5% over its length reported in A2MAC1 (750 mm). Thus, it is clear that to improve the accuracy of area measurement, the wrap dimensions must be considered instead of the flat dimensions given on A2MAC1.

The next step in defining the WSR of the hoods is to measure their surface wrap area. Provided that the scale of the image has already been defined, one can use one of the contours selections tools that pleases them more to draw the outer border of the part. Once the contour is set, the program is able to measure the area it delimits. Therefore, it is possible to

determine the hood wrap area. Figure 5 shows the contour of the Chery QQ 2010 hood. The polygon selection was used in this example.

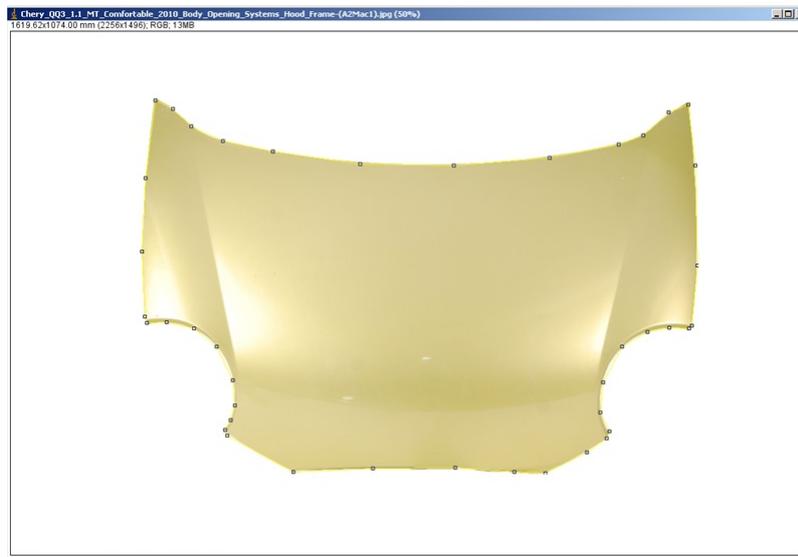


Figure 5. Contour drawing of the hood.

Once the hood wrap area have been measured, it is possible to calculate their WSRs. For this, according to the definition presented in Eq. 1, it is only necessary to calculate the ratio between the mass of the hood and its measured wrap area.

While the very definition of WSR is such that it makes it possible to compare different designs of different sizes, as the scope of vehicles whose hoods had their efficiency evaluated by this methodology is broad, for comparison purposes filters were applied in order to create subcategories that allowed a more accurate evaluation of the degree of development of the hoods of the FCA vehicles in various prices ranges.

These were the three subdivisions created:

1. HAM: Hoods made of whichever material;
2. HS: Hoods made of steel;
3. HSB: Hoods made of steel from B-Category cars.

The comparison between the different vehicles was directly made, by comparing the calculated values of WSR. The lower the WSR values, the more efficient are the hoods, and the better ranked are the vehicles.

### 3.3 DFSS – Design For Six Sigma

Chowdhury (2002) defines Six Sigma as a management philosophy focused on eliminating mistakes, waste and re-work. Where most programs focus on "offense" (making more products, increasing volume, developing lively marketing concepts), Six Sigma focus on "defense" – doing many of the things that one already does, but doing them better, with fewer mistakes.

Design For Six Sigma (DFSS) is a systematic process for design conception intended to yield robust products that meet customer expectations. Robustness is defined here as product performance that is insensitive to variation, both in manufacturing and in application environment (Dickinson, 2006). DFSS was designed to help engineers in their quest to design products right the first time and avoid quality problems at product launch (Yang and El-Haik, 2003; Taguchi *et al.*, 2000).

The original Six Sigma methodology developed for problem solving at Motorola is MAIC, which means measurement, analysis, improvement and control. Later, DMAIC instead of MAIC was advocated at GE, where D stands for definition. MAIC or DMAIC is mostly used as a unique problem-solving process in manufacturing areas. While Six Sigma is widely recognized by the DMAIC acronym, DFSS has no standard acronym. Therefore, organizations have adopted a variety of approaches that have resulted in acronyms, as follows (Shahin, 2008):

1. Define, Measure, Analyse, Design, Verify (DMADV). MADV was suggested by Motorola for DFSS, and D was added to it for definition. DMADV is similar to DMAIC;
2. Identify, Design, Optimise, Validate (IDOV). This was suggested by GE and has been used most frequently in practice;

3. Define, Initiate, Design, Execute, Sustain (DIDES). This was suggested by Qualtec Consulting Company;
4. Invent, Innovate, Develop, Optimise, Verify (IIDOV);
5. Concept development, Design development, Optimisation, Verify, Certification (CDOV);
6. Define, Characterise, Optimise, Verify (DCOV);
7. Identify, Design, Evaluate, Assure, Scale-up (IDEAS);
8. Identify, Define, Develop, Optimize, Verify (IDDOV). This was suggested by ASI Consulting Group, LLC.

In the present paper, IDDOV methodology was adopted, as this is the standard procedure at FCA US. Nevertheless, only ID phases were carried out, as the main objective of this project is to fully understand the customer requirements and rank existent measures and functional requirements according to the importance the customer gives them. Through the use of this strategy, it is not only possible to reduce the weight of an automotive part (the hood, in the case of this paper), but also not to lose sight of the other measures related to the design that might play an important role on the customer perceived quality of that specific part – and of the vehicle as a whole.

In Fig. 6 the general framework for an IDDOV project is shown. Only ID phases are presented.

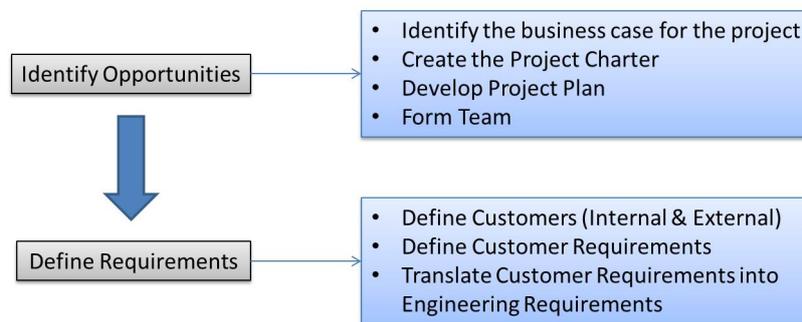


Figure 6. DFSS IDDOV Methodology – General Framework for ID Phases.

The methods used in this work are presented in the following sections.

### 3.3.1 Identify Phase

In Identify Phase, the project plan is developed, and scope and project measures are defined. That's the phase in which one defines the project objectives and deliverables and forms the project team. It basically consists in defining what needs to be done, by whom e by when.

All decisions made in this phase were a consensus between the project stakeholders, mainly the Project Leader and his Co-Coach. Summary of the kind of information collected can be seen in Fig. 7.

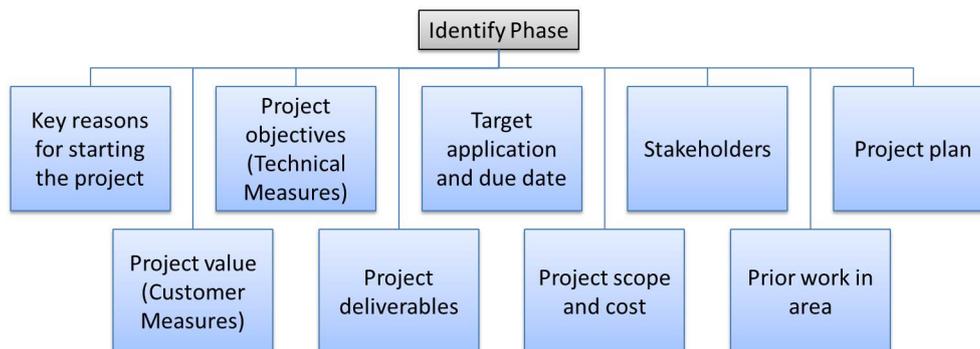


Figure 7. DFSS IDDOV Methodology – Identify Phase Deliverables.

### 3.3.2 Define Phase

Two clearly defined steps comprise the Define Phase in a DFSS IDDOV Project. They are called QFD Phase I and QFD Phase II, where QFD stands for Quality for Design. A list of all information collected through these processes is shown in Fig. 8.

In QFD Phase I, internal and external customers are identified and their wants-&-needs are determined (Customer Requirements, also broadly known as Voice of the Customer – VOC. Both terminologies will be used in this paper). All

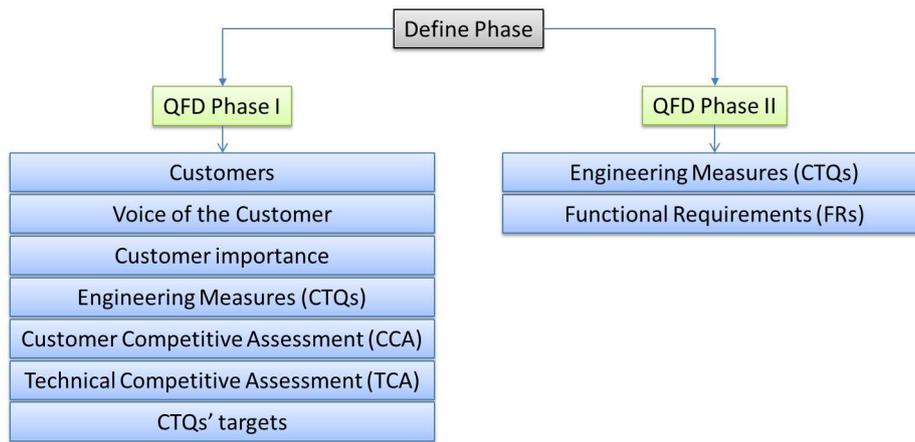


Figure 8. DFSS IDDOV Methodology – Define Phase Deliverables.

information is then translated into engineering metrics that can be properly measured (Engineering Requirements, also known as Critical to Quality – CTQ. Both terminologies will be used in this paper). CTQs form the basis to assemble the House of Quality (HOQ), which is a matrix that organizes information and helps define the project targets. Once HOQ is assembled, QFD Phase I is done.

Information used to assemble the HOQ was taken from different sources, as follows:

1. Voices of the Customer: Synthesized from previously undertaken DFSS Projects;
2. Customer Requirements Importance: e-mail survey (sent to Vehicle Owners, Body Engineers, Manufacturing Engineers and Virtual Analysis Engineers);
3. Engineer Requirements (CTQs): Most are virtual tests run by LATAM CAE Team, but they also include CAD Team evaluations and Physical Tests (which were avoided whenever possible);
4. Customer Competitive Assessment (CCA): Showroom made in front of LATAM Teardown Office, which included GM ONIX, FORD KA, PEUGEOT 208, TOYOTA ETIOS and FIAT ARGO. Most people that attended were LATAM BIW Closure Engineers;
5. Technical Competitive Assessment (TCA): was not made.
6. Relationships Matrix (define the existent relations between VOCs and CTQs): made by the author, with the help of LATAM BIW Closures Engineering;
7. Correlation Matrix (define the existent relations between CTQs): made by the author, with the help of LATAM BIW Closures Engineering;
8. CTQs Target Values: copied from the standards from which the virtual tests were taken.

The identified CTQs are deployed to QFD Phase II. They are then translated into Functional Requirements (FR), also known as Basic Functions, which are a solution neutral statement of "what a system does" – usually expressed as an active verb-noun phrase. CTQs and FRs are organized in a matrix called HOQ#2, where the correlations between them are defined.

In the present work, FRs were created by the author with the help of LATAM BIW Closures Engineering. As made in QFD Phase I, the relationships between CTQs and FRs were also identified.

Figures 9 and 10 show the roadmap for the Define Phase and the graphical mapping from VOCs to FRs.

#### 4. RESULTS AND DISCUSSION

The results of the weight efficiency measurement and of the DFSS Project will be presented, separately, in the following sections.

##### 4.1 Hood Weight Efficiency

Over fifty hoods were evaluated according to the methodology described in this paper, which in itself is a very fruitful result for the FCA Group, since now there is a database of values of weight efficiency that allows a quickly evaluation of the degree of development of the group's vehicles vis-à-vis its competitors.

The results will be presented according to the classification described in the item Methodology.

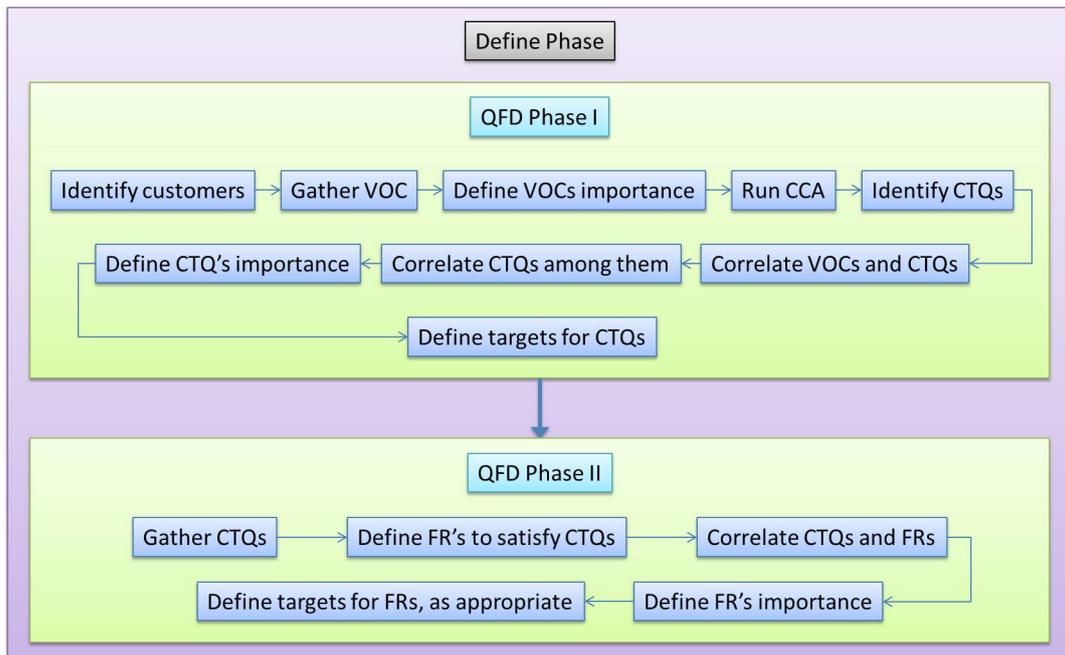


Figure 9. DFSS IDDOV Methodology – Define Phase Roadmap.

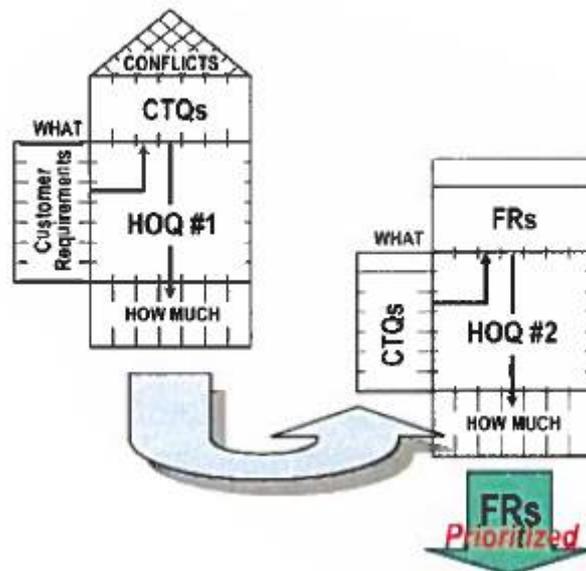


Figure 10. DFSS IDDOV Methodology – Customer Requirements to Functional Requirements Mapping (ASI, 2008).

Table 4. Top 5 vehicle hoods for HAM Category.

Model	Smart ForTwo	Citröen C4 Hatch	Audi Q3	Citröen C4 Lounge	Toyota Prius
Model Year	2015	2012	2015	2013	2016
Class	A	C	C	C	C
Material	Plastic	Alumimum	Alumimum	Alumimum	Alumimum
Area [m <sup>2</sup> ]	0.64	1.30	1.65	1.07	1.06
Mass [kg]	2.3	6.8	9.1	5.9	5.9
WSR [kg / m <sup>2</sup> ]	3.56	5.21	5.49	5.54	5.57

#### 4.1.1 HAM – Hoods made of whichever material

For the vehicles grouped as HAM (all vehicles evaluated), the WSR measurement results are presented in Tab. 4. It can be noted that there is no hood made of steel in the list, which corroborates the thesis that the use of alternative

materials has a great potential of weight saving in automotive bodies.

The top-rated vehicle in this category has a plastic-made hood, which explains why it is 35% more efficient on average than its aluminum competitors. This is a notable exception to the rule, since the use of plastic in automotive hoods is not usual.

#### 4.1.2 HS – Hoods made of steel

Table 5 shows the results obtained from the application of the present methodology to the vehicles of the HS group (only steel made hoods).

Table 5. Top 5 vehicle hoods for HS Category

Model	Tesla Model X	Mercedes GL Class	Honda HRV	Chery QQ	Mitsubish I-Miev
Model Year	2016	2015	2015	2012	2013
Class	-	C	B	A	B
Material	Steel	Steel	Steel	Steel	Steel
Area [m <sup>2</sup> ]	1.83	1.90	1.35	0.66	0.32
Mass [kg]	12.7	14.7	10.9	5.6	2.8
WSR [kg / m <sup>2</sup> ]	6.92	7.74	8.06	8.58	8.78

The WSR found for the most efficient hood of this category (Tesla Model X - WSR 6.92 kg / m<sup>2</sup>) is still about 25% lower than the 5<sup>th</sup> most efficient model in the HAM group (Toyota Prius - WSR 5.57 kg / m<sup>2</sup>). It adds further evidence that there is a great potential of weight saving in adopting materials lighter than steel (in this example, Toyota Prius has an aluminum hood).

#### 4.1.3 HSB – Hoods made of steel from B-Class vehicles

Table 6 shows the results obtained from the application of this methodology for vehicles grouped as HSB (category B vehicles with steel made hoods).

Table 6. Top 5 vehicle hoods for HSB Category

Model	Honda HRV	Mitsubish I-Miev	Peugeot 2008	Susuki Swift	Chevrolet Onix
Model Year	2015	2013	2015	2016	2014
Class	B	B	B	B	B
Material	Steel	Steel	Steel	Steel	Steel
Area [m <sup>2</sup> ]	1.35	0.32	1.20	1.07	0.98
Mass [kg]	10.9	2.8	10.6	9.4	10.5
WSR [kg / m <sup>2</sup> ]	8.06	8.78	8.78	8.85	10.66

Note: Table shows the four most efficient steel made hoods, from B-Class vehicles, plus GM ONIX. Such inclusion was motivated by the fact that this is currently the most sold car in Brazil

Firstly, it is worth noting that none of the cars in this category is among the most efficient ones (note that there is no intersection between Tabs. 4 and 6). Considering that the vehicles of this category have the largest sales volume in the market, an effort to reduce the hood weight (or any other closure weight, for that matter) could bring tangible benefits to the environment. It is often a good idea focus on vehicles with larger scales of production, so that the good effects of weight saving can be multiplied.

The results of this group can also be used to define targets for benchmarking actions, a standard procedure in the automotive industry.

## 4.2 DFSS Results

As mentioned, the main objective of this DFSS project is to serve as a guide to develop a lightweight concept of an automotive hood, without losing sight of other engineering measures that are relevant to the quality of the product.

The designing process at FCA LATAM, and at many automakers worldwide, is strongly based on internal standards, that specify tests that should be done on a vehicle part and goals for each one of them. As explained in Section Methods, the CTQs for this project came directly from these specifications, which lets no much room for targets adjustments.

That being so, the results presented in this section that are most relevant are not the targets in itself, but what CTQs and FRs are the most important to make sure the customer is happy with the product. That is a very important information, as

can help the Engineering Team to decide which path to take in order to reduce the hood weight while keeping, or ideally improving, the quality of that part.

While a DFSS Project at FCA is usually comprised of five different phases (IDDOV), the present paper will synthesize the results obtained from the application of the first two phases, Identify and Define, focusing on the Define Phase results.

#### 4.2.1 Define Customers

Identified customers were divided into groups, showed as follows.

- Internal Customers
  - Body Engineering (Closures)
  - Manufacturing (ASME and AME)
  - Vehicle Safety (Ped Pro)
- External Customers
  - Vehicle owners

#### 4.2.2 Customer Requirements – VOCs

After continuous refinement, 36 VOCs were used in this project. Real customers were surveyed to identify the importance of each one of these VOCs, and the six most important are presented in Fig. 11.

Voice Of The Customer	
VOC 1	- I want my hood to close easily from the outside
VOC 2	- I want my hood to not rust (corrode)
VOC 28	- I want my hood to function for the life of the vehicle
VOC 30	- I want all of my hood trim parts to stay firmly attached
VOC 34	- I want my hood to protect pedestrians at impact
VOC 35	- I want my hood to protect me in an accident

Figure 11. The six most important VOCs.

It can be seen that one of the VOCs is related to the usage of the hood, three are related to the part's lifecycle and two are related to safety concerns in the event of a crash.

#### 4.2.3 Engineering Requirements – CTQs

For the hood, 42 Engineering Requirements were identified, most of them Virtual Tests run by LATAM CAE Team. The most important CTQs are shown in Fig. 12.

Engineering Requirements	
F	- Permanent set due to concentrated load
G	- Exterior panel buckling load
J	- Hood first natural frequency
O	- Skin attachment stiffness
S	- Hinge attachment stiffness
AF	- Self closing height
AJ	- Simulated corrosion level @ 10 yr functioning

Figure 12. Most important Engineering Requirements (CTQs).

Most of the tests listed in Fig. 12 are designed to measure whether the hood is capable of withstanding external loads without deforming too much or being damaged.

#### 4.2.4 Functional Requirements – FRs

Based on the CTQs, 40 Functional Requirements were developed to describe the hood basic functions. The most important ones are listed on Fig. 13. It can be seen that they are related to safety, durability and ease of use. This was expected, given that the customer deems VOCs related to these items great importance.

Functional Requirements	
D	- Withstand external pressure applied
E	- Withstand external forces applied
S	- Close from the open position
V	- Avoid collisions during misuse closing
AM	- Controllably deform during pedestrian hit

Figure 13. Most important Functional Requirements (FRs).

## 5. CONCLUSION

The present work had the objective of describing the implementation of an analysis and comparison methodology of the material usage efficiency, or weight efficiency, in automotive hoods. Such methodology, which has been adapted from what is currently carried out at the FCA Detroit plant, can also be used to analyze the other vehicle closures.

It was also an objective to describe the methodology applied in the scope of this project to help FCA Engineering Team meet the weight saving needs while keeping the quality of the product. To do so, a DFSS project was launched.

The analyzes further corroborate the fact that the use of lighter materials, alternative to steel, can lead to significant weight reductions. If one compares the WSR of the most efficient vehicle among all evaluated and the most efficient vehicle among those who have steel hood, Smart ForTwo and Tesla Model X, respectively, it can be seen that the WSR of the first one is 49% smaller than that of the second.

The results provided by the use of the DFSS methodology indicate that the customer deem usability, safety and lifespan a great importance. VOCs related to these characteristics were ranked the most important among them all, which explain why CTQs like "Corrosion Life" are ranked among the most important.

It can lead to a myriad of conclusions. One, for instance, is that weight saving proposals that reduce the fatigue life of the hood should not be undertaken – even if the fatigue life meets FCA standards – once that the hood lifespan is so much important for the customer.

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