Characterization of Street motorcycles for Development of a Hybridization Kit

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***Abstract*—The analysis of mobility and pollution problems in Colombia has demonstrated that motorcycles are one of the most relevant contamination sources due to its high number of units in the market. Therefore, it is necessary to develop a solution for the problem of contamination related to this means of transport, specially for secondary cities where the number of motorcycles exceeds the number of other particular or massive means of transport. This document describes the first steps of a development process for a standard electric hybridization kit, that is a set of parts that will be adaptable to different motorcycles of the same segment, starting from the problem definition to the first functional analysis. The selection of the type of motorcycle to be converted, in order to obtain a big impact in the Colombian market, leads up to the Street type segment with Internal Combustion Engines (ICEs) of light displacement. Then, a characterization analysis is carried out in order to define common interfaces and interactions between the hybridization kit and the selected motorcycles. Besides, the users acceptance of hybrid technology, in an intermediate city in Colombia, has been analyzed, followed by the establishment of requirements and Product Design Specifications (PDS) for the development of the hybridization kit. Finally, a function structure is proposed for further development.**

***Keywords*—Hybrid Motorcycles, Street Motorcycles, Conversion Kit, Characterization, Hybridization.**

I. Introduction

Mobility has become one of the most discussed topics in the world, especially urban mobility, due to the increase of both the use of particular means of transport and environmental pollution. These problems have led the leaders of the cities to start thinking about how to respond to this increase, through some solutions such as rationalization of the car, the prioritization of public transport, the circulation of means of transport with other technologies, and implementation of renewable energy sources. The latter considering that there is an aspect of high importance directly related to the environmental pollution problem.

In order to propose a solution to the environmental pollution, new technologies, so called environmentally friendly, have been developed and produced, such as electric and hybrid vehicles, also as a different option from the traditional vehicles with contaminating Internal Combustion Engine (ICE). These options have some advantages in comparison to traditional vehicles such as a greater efficiency in the consumption of fuel of the ICE, reduction of the polluting emissions, less noise, more torque and elasticity than a conventional engine, greater smoothness and facility of use, and, better operation in short routes without using the thermal engine avoiding that it works in cold state and diminishing the wearing down [1].

In Colombia, in 2005, 64% of the vehicle fleet for private service for passengers was represented by cars [2], but in 2015 according to the survey of Quality of Life, of the National Administrative Department of Statistics (DANE), one of seven Colombians used a motorcycle for transportation, representing about 23.3% of all households [3]. Even if electric and hybrid solutions have been mostly focused on private cars and public transport, there is an opportunity for research and development in the conversion of the current motorbikes fleet. This proposal is especially valuable for secondary cities where there are more motorcycles than cars, and where this means of transport is used for work and family requirements, and preferred for economy, low costs, and agility. In this way, it is important to identify and select a group of motorcycles with common characteristics to be modified with a standard electric hybridization kit, considering technical, economic, legal and social issues. Such a product could impact about 70% of the motorcycles transiting in the Colombian roads.

This document is oriented, as a first step of the development process of a standard hybridization kit, to define a group of motorcycles of the Colombian fleet with high impact on pollution generation and market, to identify common characteristics between them, and to analyze the acceptance of this kind of solutions in Magangué, a secondary city in Colombia, where motorcycles are the principal means of transportation. Finally, a list of requirements, a Product Design Specification (PDS), and a function structure are presented, as a basis for the design process of the hybridization kit.

II. State of the art

This chapter presents a compilation of some hybrid motorcycles available on the market, and prototypes and concept designs found in scientific articles, specifically related to conversions of different types of motorcycles.

A. Commercial Hybrid Motorcycles

Asian companies are covering the hybrid motorcycle market at present since they are the largest manufacturers of this

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means of transport. Yamaha was the first to announce the Gen Ryu in 2005, and during the following decade numerous patents were registered by Honda, Kawasaki and Suzuki. In like manner, in 2010, the Italian brand Piaggio announced its model of hybrid 3-wheel scooter [4]. Honda announced its hybrid scooter Honda PCX, in 2018, as a powerful motorcycle with low emissions and low consumption, consisting of a 125 c.c. 4-stroke engine, and an electric motor. Honda also presented the Furion M1, a high cylinder (650 c.c.) motorcycle with a power of 180 hp in its thermal engine and an electric motor.

The development of hybrid motorcycles has also been a reason for the union of great brands, for example the TVS Zeppelin concept, resulting from the union of the Asian brand TVS with BMW. This reference has a starter motor that works as an alternator, and, a combustion engine that recharges the batteries with the energy produced. This development is called E-Boost technology.

In summary, the commercial offer of hybrid motorcycles demonstrates the impact and interest of the market in this type of vehicles. However, all these products are developed from scratch, and conversion kits are still a valuable proposal for conversion of internal combustion motorcycle already in the market.

B. Converted hybrid bikes and prototypes

In 2007, Tong and Jwo [5] worked on a 50 c.c. scooter motorcycle. The main purpose of the hybridization was to bring the performance of the motorcycle to the levels of a 100 c.c. version, but with the advantages of the higher efficiency of the hybrid powertrain. The prototype was designed with both engines working on the rear wheel, so that the torque is added and the bike has better acceleration and performance, as well as higher overall efficiency, aiming at a consumer-friendly system. They implemented an electric motor of 500W, to supply the difference in torque between the 50 c.c. and the 100 c.c. scooter, so it could reach the same top speed and had the same peak torque. In their tests they achieved a 35% increase in the efficiency of the motorcycle. It should be noticed that this prototype was not connectable to the electric network for recharging, but the ICE recharged the batteries.

In 2010, Hsu and Lu [6] carried out a project that included the design and prototyping of a hybrid motorcycle, which used a 125 c.c. 4-stroke ICE manufactured by the Yamaha company, an electric motor, and a Continuous Variable Transmission (CVT). From this conversion, it was obtained that the amount of discharge of exhaust gas emissions can be effectively reduced, and the hybrid mode effectively consumes less fuel than the consumption in the ICE mode. In addition, the experimental results obtained by the ECE-40 test cycle in hybrid mode showed that the time of engine shutdown is approximately 47.5% of the total time of the experiment.

In 2013, Asaei and Habibidoost [7] designed, simulated and prototyped a hybrid motorcycle. In this project, the authors decided to carry out the study on a scooter-type motorcycle with a 125 c.c. engine and automatic CVT. For the electric part, a 500W hub motor was selected for the front wheel [7]. The engine sizing was carried out based on the basic functions defined for the electric motor: move the motorcycle at low speed and low torque demand, work as a regenerative brake, and assist the combustion engine in a high acceleration mode. They simulated the motorcycle with both the conventional ICE and with the hybrid power train, under two different driving cycles: one similar to urban traffic (ECE), and another similar to highway traffic (CYC_ARTERIAL). They concluded that, if the motorcycle is to be used in urban environments, the energy savings and emissions reduction will be considerable; on the contrary, for highway use over long periods of time, the change would not be justified. Furthermore, they mentioned that having a smaller combustion engine and a larger electric motor could lead to better results.

In 2014, Morandin et al. [8] designed, simulated and prototyped an Aprilia RS4 hybrid motorcycle, with a 125 c.c. ICE, an electric motor, and the original transmission of the motorcycle. The objective of carrying out the hybridization process was to improve the performance of the reference motorcycle in terms of torque, especially at low rpm, by replacing the original electric alternator with a new electric motor. The main requirements of this project were low weight and volume of the energy storage system. The experimental results confirmed that the final torque profile matches the design expectations. Acceleration time (from 0 to 60 km/h) decreases by 16%, and maximum speed increases by 18%; furthermore, these performances were achieved by increasing the total weight of the vehicle by only 15%.

In 2019, Chen et al. [9] designed, simulated and prototyped a hybrid motorcycle. The project was developed with a 150 c.c. ICE (GRAND DINK 150) manufactured by Kwang Yang Motor Co., an electric motor, and a CVT. They found that the idling stop could be achieved to reduce fuel consumption and exhaust gas/pollution emissions, and the theoretical analysis carried out based on the experimental data showed that the total efficiency of energy use in the driving test was 55.93%. In terms of the efficiency of the mechanical transmission, calculations with the theoretical maximum speed and the maximum tested speed showed that the efficiency loss was approximately 8.75%, which was caused by the slip loss of the belt of the CVT.

In 2020, Polanía et al. [10], [11] developed a hybridization kit for conversion of a Street type motorcycle with a 125 c.c. ICE, installing a 3 kW electric hub motor in the rear wheel powered by a lithium battery. Such approach allowed to drive the motorcycle in electric mode for speeds under 20 km/h, specially for urban driving cycles, and powered by the ICE for higher speeds.

From all the studies and developments, it is evident that in most of the cases a CVT is used, because it facilitates the coupling of the engines. It is also observed that all the designs implemented in the motorcycles to perform the hybridization are unique, none of them has been replicable to other motorcycle references. In this way, no studies, focused on achieving a standardized hybridization kit or process to be

implemented on different motorcycles, have been found.

III. Analysis of the Motorcycles Segment in Colombia

The first step in the development process of an electric hybridization kit for motorcycle conversion is to analyze the current vehicle fleet in Colombia in order to determine a big impact in the market, and an important reduction in pollution produced by this means of transport. The information analyzed of the motorcycle market has been provided by Fenalco [12], which is a Colombian entity that seeks the development of trade, and, Andemos Colombia [13], which is the Colombian association of sustainable mobility.

Figure 1 presents the motorcycles market, accumulated in 2019, classified according to the engine displacement, and it is possible to conclude that almost 68% of the registered motorcycles have engine displacements below 135 c.c. Also, it is observed that the other ranges contribute less than 13% each. Therefore, it is evident that a hybrid conversion in the range of 0-135 c.c. impacts the most significant portion of the motorcycle park.

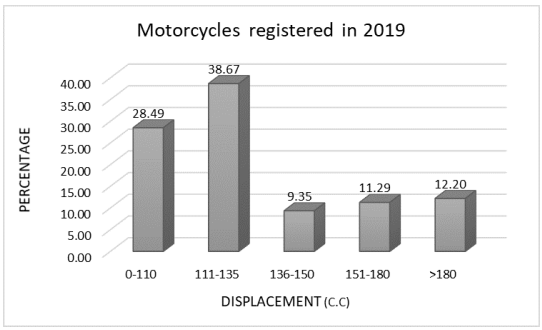

Fig. 1: Motorcycles market distribution according to engine displacement

Figure 2 presents the motorcycle market classified according to the segment, and it is possible to conclude that the Street category, defined by the ANDI (National Association of Businessmen of Colombia) as motorcycles adapted for the street and work, covers the 74% of the registered motorcycles of the motorcycle fleet.

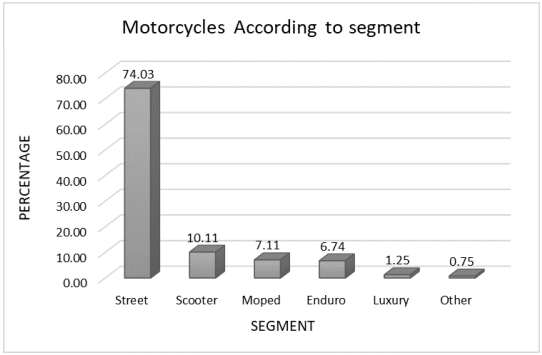

Fig. 2: Motorcycles market distribution by segment

Considering the information supplied by Fenalco [14] about the percentage of the Street type motorcycles in 2017 and 2018, this trend is maintained about a 70%. Besides, the information of the most sold motorcycles has also been reviewed, and it was found that the street category corresponds to the highest amount registered in the market. Figure 3 presents the ten most sold motorcycles in Colombia in 2019, and it is observed that around 62 % of the motorcycles belong to the street segment. In addition, the first three street motorcycles are in the range of 0-135 c.c. This reaffirms the idea of developing a standard kit for these street motorcycles.

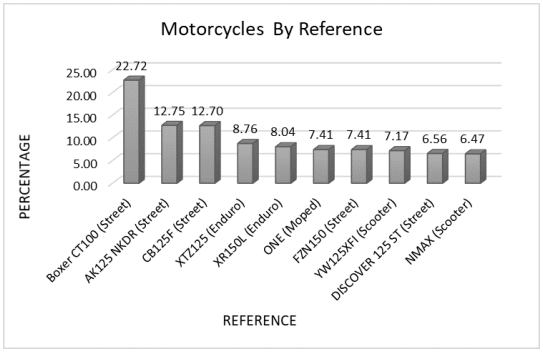

Fig. 3: Best selling motorcycles in Colombia.

According to the aforementioned information, authors have selected four street motorcycles, with engine displacement between 100 and 135 c.c., which would be considered for the hybridization process: Boxer CT100 and Discover 125ST from Auteco company, NKD 125 from AKT company, and CB125F from Honda company.

IV. Characterization of Street Motorcycles

In this chapter two different characterizations, mechanical and dimensional, are carried out to establish similarities and differences between the four selected street motorcycles, in order to allow the hybridization kit to be applicable to all the references.

A. Mechanical characterization

Table I summarizes the values for different common mechanical variables for all the four selected street motorcycles.

It is observed that all motorcycles work with a 4-stroke engine, their cylinder capacity varies from 100cc-125cc, their transmission is mechanical, and the gearbox is similar.

The weight is in a range from 95 kg to 128 kg, the torque is between 8 Nm and 10.8 Nm, the lowest power is 8.09 hp and the highest power is 12.8 hp.

Also, the front suspension coincides in all motorcycle references, as well as the braking system of all. The rear suspension and the compression ratio only differ in the Discover reference. The load capacity works in the range of 130 to 170 kg. These data are important when assembling components on the motorcycles because they are related to fuel consumption and effects that may have on the damping. But, in general, the motorcycles are very similar.

TABLE I: Mechanical characterization

	Boxer CT100	AK125 NKD	CB125f	Discover
Engine	4 stroke / single-cylinder	4 stroke / OHV	4 stroke / OHC	4 stroke / single-cylinder
Displacement (cc)	99.27	125	124.8	124.59
Transmission	Mechanical / 4 speeds	Mechanical / 5 speeds	Mechanical / 5 speeds	Mechanical / 5 speeds
Fuel Tank Capacity (Gal)	2.7	2.6	3.4	2.64
Net weight (kg)	109	94.5	128	125
Max torque (Nm)	8.05 @ 4500 rpm	9.3 @ 7000 rpm	10,11 @ 5.000 rpm	10.8 @ 6500 rpm
Max power (hp)	8.09 @7500 rpm	10.34 @ 8000 rpm	10.5 @ 7.750 rpm	12.82 @ 9000 rpm
Charge capacity (kg)	150	130	173	130
Compression ratio	9.5 +/- 5.1:1	9.5:1	9.5:1	9.8 +/- 0.5:1
Front suspension	Hydraulic telescopic	Hydraulic telescopic	Hydraulic telescopic	Hydraulic telescopic
Back suspension	Double shock absorber	Double shock absorber	Double shock absorber	Mono shock absorber
Brake	Front - Disc Back- Drum	Front - Disc Back- Drum	Front - Disc Back- Drum	Front - Disc Back- Drum
Rim (inches)	17	18	18	17

B. Dimensional characterization

The Table II presents the main dimensions of the four selected motorcycles necessary for the dimensioning and positioning of the different components of the standard hybridization kit.

TABLE II: Dimensional characterization

	Boxer CT100	AK125 NKD	CB125F	Discover
Total length (mm)	1965	1900	2035	1980
Total height (mm)	1070	800	1080	1078
Total width (mm)	770	770	765	714
Wheelbase (mm)	1235	1270	1310	1306

It is observed that the differences in the measurements are not considerable, remaining in similar ranges. The NKD125 is the most compact motorcycle, and the CB125F is the biggest one, in almost all their measurements, with respect to the others. The Discover 125 is the thinnest motorcycle.

The dimensional characterization of the motorcycle is important because at the time of making mathematical models, simulations or prototypes, it serves to estimate the center of gravity, the effect of added masses, and also allows to modify forces applied to the motorcycle elements, such as the rims.

V. Market analysis in the intermediate city Magangué

An intermediate city has a population between 100,000 and 1 million inhabitants. Currently, Colombia has 57 intermediate cities that will be the protagonists of rapid growth that requires management and will represent a challenge for sustainability and urban planning [15].

Magangué is a Colombian municipality located on the banks of the Magdalena River, in the department of Bolívar, where it is the second most populated city with a projected population of 123,986 by 2020 [16].

Besides, it is estimated that there are just over 20,000 motorcycles of Street type [17], with the motorcycle being considered the predominant means of transport in this city. With this in mind, a market study has been carried out in order to obtain information on the context and also to find out what user requirements should be considered.

As a plan of action, surveys were carried out to obtain information from both the user and the owner of the motorbike, which was representative for the planning and justification of the hybridization kit. For this purpose, a sample of 50 people was taken, 44% women and 56% men, with ages between 18 and 45 years. Answers were collected in strategic points with high flow of motorcycles and users, specifically in the Magangué harbor where the transport terminal is located, the main shopping centre, and the main Avenue.

A. Surveys

The representative questions of the analysis of mobility in Magangue related to user perception, transport needs and acceptance of new technologies are the following:

- How many days do you use your motorcycle per week?
- How many people normally ride your motorcycle?
- Disposition to add a less polluting technology to your motorcycle ?

Results showed that the motorcycle remains in continuous use during the week, confirming that it is the most used means of transport. In most cases the motorcycle carries two passengers, according to the traffic regulations, but in other cases the conditions of use are not the most suitable for which a motorcycle is designed, for example, 3 people and luggage. Positive responses to a new technology that can help with environmental pollution were common in the survey, and negative responses were justified by the fact that, although the motorcycle pollutes, they consider that it does not do it so to any great extent.

B. Observations on strategic points and focus group

In addition, a focus group was held with twelve persons who work with their motorcycles in the transportation of passengers (motorcycle taxi drivers) to listen to their needs with respect to the vehicle functionality, and some observations were carried out at the same strategic points of the surveys. Most representative results are the following:

- The most common motorcycles are the references “Boxer”, “Platinum” and “Discover”.
- On average, the life cycle of the motorcycles is between 5 and 6 years of use. Normally this is the time estimated for the motorcycles that provide the motorcycle taxi service, which are the majority, considering that this is the main source of work.
- The average ride is between 200 and 300 km per day.
- The issue of funding was highlighted in the discussions, as the purchasing power of the population is low and this is an important factor as it indicates that the kit should have as few interventions, components and low cost as possible.
- The electricity service is an intermittent service and the permanent availability is not assured in this area, so it is necessary that the hybridization kit also allows the traction of the motorcycle only with the combustion

engine, as well as the possibility of charging system by regenerative braking.

In relation to the information analyzed in the market study of the Colombian vehicle fleet, it is evident that the most relevant motorcycles in Magangué fit the conditions found in the previous market study, which are the type and range of engine displacement.

Due to the relationship found between the motorcycles, it was decided to additionally quantify the distribution, sales and maintenance centers, since they are directly related to any modification or repair that is necessary for this means of transport, especially with a hybridization process or kit of a motorcycle and its components. In this intermediate city there are 9 authorized distribution centers for spare parts, 3 authorized service centers, and 2 points of sale of different motorcycles brand . Additionally, there are 16 warehouses and distribution centers for motorcycles and spare parts of the brand Auteco in the influence area of Magangué. This shows that there is a greater number of workshops of this brand since this is the leading brand in sales of the municipality, as well as in the country.

VI. Product design specification (PDS)

For the elaboration of the PDS, the methodology proposed by Pugh [18] was used in order to identify a list of requirements applicable to the hybridization kit. These were grouped by categories such as cost, performance, maintenance, and environment, to which Specifications were established to define the design parameters of the kit.

Each requirement and specification listed in the Table III are result of the studies carried out previously, and the ranges are related to the technical, mechanical and dimensional characterization. In addition, the maintenance issue was deepened with the manuals of workshop of each motorcycle, and with motorcycles technicians, in order to have arguments for the definition of these values.

There are challenges in the design of the kit such as: the kit should not affect the costs, maintenance times or useful life of the motorcycle components. In addition, the motorcycle should have mechanical and energy performance equal to or higher than the original bike. The hybridization kit should not affect the safety, ergonomics or aesthetics of the motorcycle, and, finally, it should seek simplicity in manufacturing and assembly.

VII. Functional analysis of the hybridization kit

The process of implementing a hybrid powertrain in a mechanical motorcycle involves making a set of modifications, because there are two engines with totally different characteristics. A functional analysis is started with a transparent box, presented in the Figure 4, in order to identify functions executed by the kit, with their related energy, matter and information flows.

It is noticed that there are functions to which a mechanical component is easily associated, as the electric motor. However, there are others in which the solution is not as evident as the element where the energy of both motors is coupled.

TABLE III: Product Design Specifications for the Hybridization Kit

Category of requirement	Consumer requirements for the kit	Specifications	Units	Value
Target cost	The value of the kit should not exceed half of the commercial value of the bike.	Total cost of the kit.	$ COP	1'645.000 <X <2'450.000
Performance	The kit should make the bike more efficient.	Equivalent energy efficiency.	Km/Gal	128 <x <175
		Total mass increase.	kg	14.2 <x <19.2
	The kit must withstand water, dust and temperature.	IP protection grade.	IP rating	x = IP 55
	Improves the acceleration of the bike.	Total mass increase.	kg	14.2 <x <19.2
		Maximum torque.	N.m	8.05 <x <10.8
	Maintain the speed of the motorcycle.	Maximum power.	HP	8.09 <x <12.82
	Maintain the motorcycle's range.	Equivalent energy efficiency.	Km/Gal	128 <x <175
	The kit must have a minimum energy consumption.	General energy efficiency.	%	x>= 0.5(total energy)
Lifetime	The kit must maintain the warranty and originality of the bike.	Lifetime of electrical machines.	km	x >= 20.000
		Service life of mechanical components.	km	x >= 20.000
		Service life of main transmission wear elements.	km	x >=5.000
		Service life of wear elements of the brake system.	km	x >=5.000
Manufacturing facility	Be minimally invasive on the parts of the bike.	Modifications to the original bike.	#	x<10
	Must be standard for a street-level motorcycle group.	Street segment motorcycles.	#	x>=4
	The kit must be adjusted to the technical characteristics of the four motorcycles.			
	The kit must be available at a spare parts store.			
	The kit does not require specialized tools for installation.	Specialized tools.	#	x <2
	Easy to assemble and disassemble.	Time required to install the kit.	h/man	x<10
Environment	Greener motorcycle.	Reduction of hydrocarbons per km.	%	x>=20
		Carbon monoxide reduction per km.	%	x>=20
	It should not be noisy.	Intensity	db	x <86
Maintenance	Be maintainable.	Time required to do maintenance.	h/man	x<3
	It should not have long maintenance times.			
	The kit does not require specialized tools for maintenance.	Specialized tools.	#	x <2
	Easy to clean and wash.			
	Easy visual inspection of the kit.	Time required to make the visual inspection.	h/man	x<0.25
Dimensions and weights	The kit must maintain the motorcycle's load capacity.	Maximum weight allowed.	kg	130<x<173
	The kit must not alter the load of either a passenger or baggage.		kg	130 - kit <x<173 - kit
	Do not increase the original dimensions of the motorcycle.	Maximum length allowed.	mm	1900 <x <2035
		Maximum height allowed.	mm	800 <x <1080
		Maximum width allowed.	mm	714 <x <770
		Maximum allowed wheelbase.	mm	1235 <x <1310
	It must be compact.	Busy volume on the motorcycle.	L	x <40
Comfort and safety	The kit must maintain the motorcycle's rideability.	Center of gravity.	#	x<=x motorcycle
	It must be safe.	Safety factor.	#	x<= 2

VIII. Conclusions and Future Work

The analysis of the State of the Art has demonstrated that a hybrid motorcycle have benefits such as an increase in motorcycle efficiency between 35% and 55%, decrease in polluting gases due to combustion engine shutdown times during hybrid driving, and reduction in fuel consumption in relation to a combustion engine motorcycle, justifying the development process of a standard hybridization kit for modification of the current fleet of motorcycles in Colombia. Besides, no information was found related to a standard hybridization process for a group of motorcycles, only custom designs have been identified, and most of them concerns the electrical, electronic and control issues. In addition, these developments do not

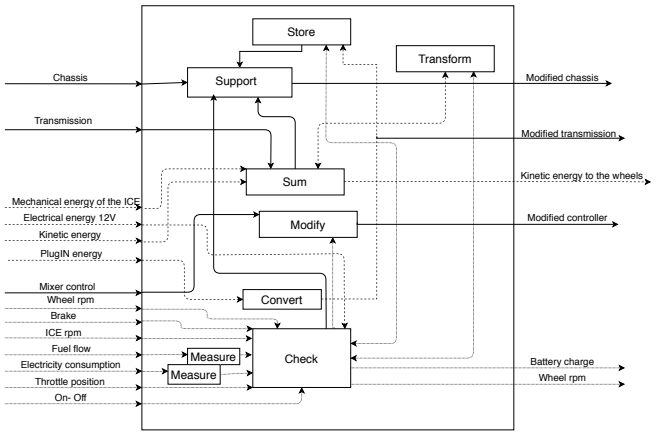

Fig. 4: Transparent kit box

coincide with the most used transmissions in the Colombian market, and especial emphasis has been found about hybrid motorcycles with CVTs instead of manual transmission ones.

The Colombian motorcycle market study and the segment analysis show that the 73% of the motorcycle fleet corresponds to the Street category, specifically in the range of 0 to 135 c.c., allowing to identify four different motorcycles to be considered in the development process of the hybridization kit. Selected motorcycles are Boxer CT100, NKD 125, CB125F, and, Discover 125ST.

The mechanical and dimensional characterization of the four selected motorcycles proved their similitude in propulsion systems, suspension, load and fuel tank capacities, brake systems, weights and general dimensions; demonstrating the feasibility of considering equal design parameters of the hybridization kit to be implemented in each motorcycle.

The market analysis carried out in the secondary city of Magangué allows to conclude that the implementation of a hybrid technology in ICE motorcycles, that is more friendly to the environment, is accepted by 96% of the population surveyed, who are the users of motorcycles. Besides, focus group and observation allow to conclude that the motorcycle is one of the most important means of transport, and that the four selected motorcycles coincide with the motorcycle park in the city, such as it is observed for the country behaviour.

The steps proposed in this document, the market analysis, the characterization of the motorcycles, the analysis of the needs and the context have allowed to define the requirements and the design specifications of the product, with their respective initial values. This information is an input for the conceptual design stage of the standard hybridization kit. In addition, the functional analysis shows the complexity of the function that the coupling of the engines fulfills, since it is not evident a mechanism that can perform this function, and, at the same time, fulfills the requirements established for the kit.

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