UNIVERSIDAD EAFIT

Engineering School

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METHODOLOGY FOR THE MODIFICATION OF THE MOTORIZATION OF A TWO-WHEELED VEHICLE CONSIDERING THE REDESIGN OF MECHANICAL SYSTEMS.

Graduation manuscript presented as partial requirement to obtain the

Master of Science in Engineering

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Abstract

With the passage of time, the use of two-wheeled vehicles in the world has increased due to the advantages of this, some are: low cost means of transports compared to a four-wheeled vehicle, low consumption, low maintenance cost, among others; by increasing the demand for this type of vehicles, it has as a consequence that its market diversifies and expands the range to cover all types of people, territories and needs, with this presents the opportunity to develop and implement a new technology, in order to carry out innovation processes and establish differences with other means of transport. This document proposes the structure of a methodology to standardize a modification in the motorization of two-wheeled vehicles, considering the design and redesign of mechanical systems, the main objective is to analyze the state of the art of existing methodologies that contain some of the processes mentioned above, then the structure of the methodology is proposed, then applied to a case study (Design of a hybridization kit for motorcycles) and finally the methodology is evaluated and the conclusions and results found in the process are presented.

Keywords: Methodology, standardization, design, redesign, modification, motorization, two-wheeler, characterization, product family, mechanical systems.

Resumen

Con el paso del tiempo, el uso de los vehículos de dos ruedas en el mundo se ha incrementado debido a las ventajas de este, algunas son: medio de transporte de bajo costo comparado con un vehículo de cuatro ruedas, poco consumo, bajo costo de mantenimiento, entre otras; al aumentar la demanda de este tipo de vehículos, tiene como consecuencia que su mercado se diversifique y amplía la gama para cubrir todo tipo de personas, territorios y necesidades, con esto se presenta la oportunidad de desarrollar e implementar una nueva tecnología, con el fin de realizar procesos de innovación y establecer diferencias con otros medios de transporte.

En este documento se propone la estructura de una metodología que permita estandarizar una modificación en la motorización de los vehiculos de dos ruedas, considerando el diseño y rediseño de los sistemas mecánicos, el objetivo principal es analizar el estado del arte de las metodologías existentes que contienen algunos de los procesos antes mencionados, luego se propone la estructura de la metodología, después se aplica a un caso de estudio (Diseño de un kit de hibridación para motocicletas) y finalmente se evalúa la metodología y se presentan las conclusiones y resultados encontrados en el proceso.

Palabras Clave: Metodología, estandarización, diseño, rediseño, modificación, motorización, vehículo de dos ruedas, caracterización, familia de productos, sistemas mecánicos.

0.1 Personal publications

A scientific article was generated and published during the development process of this research project:

Conference:

- Moreno-Durango, L. M., Osorio-Gómez, G., Córdoba-Morales, J. (2020, September). Characterization of Street motorcycles for Development of a Hybridization Kit. In 2020 9th International Conference on Renewable Energy Research and Application (ICRERA) (pp. 365-370). IEEE.

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Chapter 1

Introduction

1.1 Problem Definition

Mobility has become one of the most discussed topics in the world, especially urban mobility, due to the increase in the use of means of transport that has as a consequence an increase in environmental pollution.

These problems have led city leaders to start thinking about how to respond to this increase, through some solutions such as the rationalization of the automobile, the prioritization of public transport, the circulation of environmentally friendly means of transport and the implementation of renewable energy sources.

In order to propose a solution to the environmental pollution, environmentally friendly technologies, mentioned above such as electric and hybrid vehicles, have been developed and produced, also as a different option from the traditional vehicles with contaminating Internal Combustion Engine (ICE).

These options have some advantages compared to traditional vehicles such as higher fuel efficiency, reduced emissions, less noise, and more torque than a conventional engine ICE, greater smoothness and ease of use, and, better performance or short distances without using the thermal engine avoiding it to work in a cold state and decreasing the wear and tear (Romm and Frank, 2006).

In Colombia, in 2005, 64% of the vehicle fleet for private passenger service was represented by automobiles; by 2015, according to the Quality of Life survey of the National Administrative Department of Statistics (DANE), one out of seven Colombians used a motorcycle for transportation, which represents about 23.3% of the total households (Serpa, 2015) and, in 2021, according to the RUNT, 59% of the vehicle fleet is represented by motorcycles, which is equivalent to 9.419,374 motorcycles.

Since environmentally friendly or sustainable solutions, such as electric or hybrid, have focused mainly on private cars and public transport, there is an opportunity for research and development in a conversion or hybridization of the most representative part of the current vehicle fleet towards a less polluting means of transport, i.e. a change in the motorization of two-wheeled vehicles already on the market.

This proposal is especially valuable for cities where there are more motorcycles than cars and where this means of transportation is used for work and family needs, and is also preferred for its economy, low cost and agility.

Due to the above, it is evident the importance of a standard conversion product, applicable to the motorcycle segment, which has generated the question of how to develop a methodology to determine the process to perform a modification in the motorization of a two-wheeled vehicle, considering the interactions of mechanical systems, and also implement a solution that helps reduce pollution in the environment.

1.1.1 Theoretical Background

1.1.1.1 Hybrid Vehicles

A vehicle is called a "hybrid" when it is powered by two or more engines that may be of different natures. With this configuration, the car can take advantage of both sources to obtain energy and move. It is worth mentioning that the vehicle can circulate in combination of both engines or in purely electric form. According to Volkswagen México (1 07). These vehicles could present different architectures or configurations: series, parallel, or series-parallel.

1.1.1.2 Series Configuration

Silvaş et al. (2012) and Emadi et al. (2005) defined a series hybrid vehicle composed of only two engines that are an Electric Motor (EM) and an Internal Combustion Engine (ICE), characterized by requiring larger and more powerful engines, due to the fact that the engines are generally connected in a direct way which causes the same transmission ratio all the time.This increases the costs and weights of the vehicle. In addition, the EM is the first supplier of energy to the vehicle's wheels, which makes it lose less energy.

According to s. Williamson et al. (2006) the series topology is the least effective of the existing ones, mainly because of the additional weight of the vehicle, generating higher fuel consumption. Besides, this topology generates wear in the drive train, so in long distances of use, it is not the most appropriate.

The main advantage of the series configuration is that the combustion engine operates mostly at its optimum combination of speed and torque. It is also mentioned that a series vehicle is more used for city driving.

1.1.1.3 Parallel Configuration

A hybrid vehicle with the parallel configuration has the internal combustion engine and the electric motor mechanically connected.

The advantage is that the vehicle can run on ICE or EM and both at the same time. It is possible to freely choose the combination to supply the required amount of torque at any time.There are fewer power conversion stages compared to an electric vehicle, resulting in less loss of power, energy and consumption, according to Emadi et al. (2005).

1.1.1.4 Series-Parallel Configuration

In this series-parallel combination there is an additional mechanical link between the generator and the electric motor, compared to the series configuration, and an additional generator compared to the parallel one. It is possible to combine advantages of the series and parallel hybrid vehicle configuration, although it should be noted that the series-parallel hybrid vehicle is also relatively more complicated and expensive, because it has more parts, according to Emadi et al. (2005).

Of the vehicles available on the market, it is evident that the series-parallel configuration is the most popular.

1.1.1.5 CVT transmission

A CVT or automatic transmission does not use gears that directly connect the engine to the wheels. These gears or sprockets that determine the transmission ratio are replaced by a mechanism composed of two pulleys and a belt or chain that joins them, by means of two cones or shafts facing each other that allow changing the size or diameter of each pulley with which the ratio changes, that is, the pulleys 'stretch' or 'shrink' according to the change Avendaño (9 09).

1.1.1.6 Mechanical Transmission

A manual or mechanical transmission or gearbox has a series of gears, which, if interconnected through the use of a gearshift, allow to decrease or increase the speed. To change gears or shift, the clutch separates the gearbox from the engine at the moment of changing Kia (2 11)

1.2 Research question

Is there a methodology for the modification of mechanical systems in the engine change of a motorized two-wheeled vehicle, so that it can be standardized in a certain product segment?

The focus of this question is derived from relating a system that does not exist with another already existing, considering three different processes in the same objective: design, redesign and standardization. With a bibliographic review about modifications in the motorization of vehicles, it was evidenced that in most of these projects a methodology was not defined, that is why there is an opportunity to develop a research on this topic.

1.3 Objectives

1.3.1 General objective

To develop a methodology for the modification of the mechanical systems related to a change in the motorization of a two-wheeled vehicle, by means of an analysis of the interaction of variables between the systems of a case study and with the integration of tools used in design and redesign methodologies, which allows the standardization of the modification in a given product segment.

1.3.2 Specific objectives

- Determine the phases of a methodology for the modification of the motorization of a two-wheeled vehicle to be standardized in a product segment.

- Develop a structure for the elaboration of the methodology, containing the activities and tools used, by collecting information from case studies.

- Validate the proposed methodology by applying it to a case study of a hybridization kit that can be implemented in a given number of Street type motorcycles.

- Evaluate the methodology with qualitative indicators obtained from the perception of engineering professionals.

1.4 Research Scope

The objective of this project is to establish a design and redesign methodology focused on mechanical issues related to motorization modification processes, mainly on motorized two-wheeled vehicles, and to validate it through the implementation of a case study, using a research approach. The structure of the methodology with its phases, stages and corresponding tools will be implemented in the development of a conversion kit to hybridize a combustion motorcycle, and, finally, evaluated according to the results obtained.

1.5 Research Approach

This research is focused on the implementation of a functional product designed from scratch and its relationship with an existing environment. Therefore, the methodology of Practice Based Research was selected since it is based on principles inspired by research, designs and information gathering techniques within the existing forms of practice to answer questions arising from the same practice Horváth (2007). This methodology allows to design and redesign, and it is a methodology used for existing products.

In addition, knowledge is generated through structurally varied construction and evaluation cycles, experiences and product prototypes, as it is presented in the Figure 1.1.

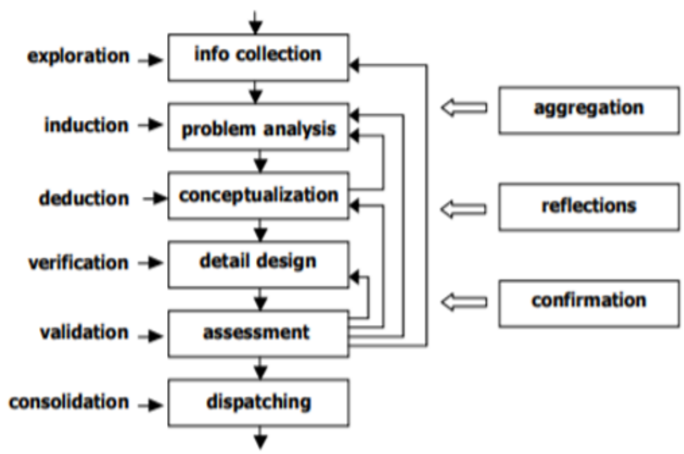


Figure 1.1: Practice-based research for Horváth (2007)

1.6 Manuscript structure

This research is organized in four different phases:

1. First phase. The background, the formulation of the problem, the theoretical framework, the literature review, the used methodology and the objectives of the study are presented in chapters 1 and 2.

2. Second phase. The approach of the methodological proposal, i.e., the structuring, description of each phase, stage and tool that comprise it and its respective justification, are presented in Chapter 3.

3. Third phase. The application of the methodology in the case study, where each phase is implemented and the results obtained throughout the process are presented in Chapter 4.

4. Fourth phase. The evaluation of the methodology; how it was evaluated, who evaluated it and the obtained results are presented in the Chapter 5.

Finally, the conclusions are presented in the Chapter 6.

Chapter 2

Literature Review

This chapter analyzes the research related to the current work, divided into the following sections.

- Section 2.1. Bibliometrics, where the combinations or search equations used for this work are shown.
- Section 2.2. Analysis of the methodologies of design, redesign and standardization of products, definition, tools, and, advantages and disadvantages of each one.
- Sections 2.3 and 2.4. Analysis of the prototypes of changes or modifications of motorization in motorized two-wheeled vehicles.
- Section 2.5. Conclusions on the state of the art: The general conclusions of the literature review and the research opportunity are presented.

The literature review of this work focuses on the methodologies used over time to develop or implement a modification in the motorization of motorized two-wheeled vehicles, with emphasis on their mechanical systems or characteristics.

2.1 Bibliometry

The first equation of the bibliographic research considers the terms Hybrid and Motorcycle, recovering approximately 64 articles. Then, a filtering was carried out, making the search equation more personalized, in order to focus on the methodological and scientific part. The search equations are presented in the Table 2.1.

The 64 articles were filtered with words such as: mechanical development or mechanical modifications, modifying the search equations with the following words: methodology, transmission, powertrain, mechanical design and modifications, among others.

Words	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Results**
Combination 1	Hybrid	**AND**	Motorcycles	**AND**	mechanics			1
Combination 2	Hybrid	**AND**	Motorcycles					64
Combination 3	Hybrid	**AND**	Motorcycles	**AND**	Transmission			8
Combination 4	Mechanics	**AND**	Motorcycles	**AND**	Hybrid	**AND**	Design	0
Combination 5	Kit	**AND**	Hybrid	**AND**	Vehicles			16
Combination 6	Kit	**AND**	Hybrid	**AND**	Motorcycles			1
Combination 7	Hybrid	**AND**	Motorcycles	**AND**	Design			82
Combination 8	Hybrid	**AND**	Motorcycles	**AND**	Design	**AND**	Transmission	13
Combination 9	Modulars	**AND**	Motorcycles	**AND**	Design			0
Combination 10	Standard	**AND**	Motorcycles	**AND**	Design	**AND**	Transmission	2
Combination 11	Standard	**AND**	Motorcycles	**AND**	Design	**AND**	hybrid	8
Combination 12	Modify	**AND**	Changes	**AND**	Motorcycles	**AND**	Mechanics	0
Combination 13	Modular	**AND**	Motorcycles	**AND**	development			6
Combination 14	Development	**AND**	Motorcycles	**AND**	Transmission			20
Combination 15	Standardization	**AND**	Tool	**AND**	mechanics	**AND**	Methodology	6
Combination 16	Standardization	**AND**	design	**AND**	mechanics	**AND**	Methodology	12
Combination 17	Standardization	**AND**	development	**AND**	mechanics	**AND**	Methodology	13
							Total	246

Table 2.1: Search equations

As words were added, the number of articles available in various engineering and science databases decreased. For the search equations related to the terms methodology, standardization and mechanics, the maximum number of results found were 13. The search with the lowest results is the one relating the terms "standardization" and "motorcycles", and those relating "hybrid kit" with "motorcycles". In this way, it is evident that there are few researches, reports or developments in these topics.

An analysis of the topics covered by the different authors shows that 6 articles include the generalities of the hybridization process, the topologies with their advantages and disadvantages, and some coupling systems used in vehicles. In addition, it becomes clear that the parallel topology is the most used in hybridization systems; due to its dimensional advantages, the number of components involved, and also the ease of installation work in the system that generates the torque. Filtering with the combinations, allowed to exclude developments dealing mainly with control or power supply, 16 articles, specific to hybrid motorcycles, were reviewed. Eleven articles deal with the hybridization of scooter-type motorcycles, i.e. working with an automatic transmission. This makes it possible to take advantage of the different spaces and operation that this type of transmission can offer. The remaining five articles apply a hybridization system in street type motorcycles, with mechanical transmission, because they have low displacement engines and their users represent a large part of the world's motorcycle fleet. Additionally, emphasis is made on the methodologies used for the development of each project mentioned above.

Of these 15 articles, only 20% are not implemented in a motorized two-wheeled vehicle, i.e., they are implemented in a test bench, since the research is related to analytical models where calculations and detailed studies of the behavior of the different components that define the operation of the system with a change of motorization are carried out.

Figure 2.1 presents countries where the major developments on motorization modifications or changes are found.

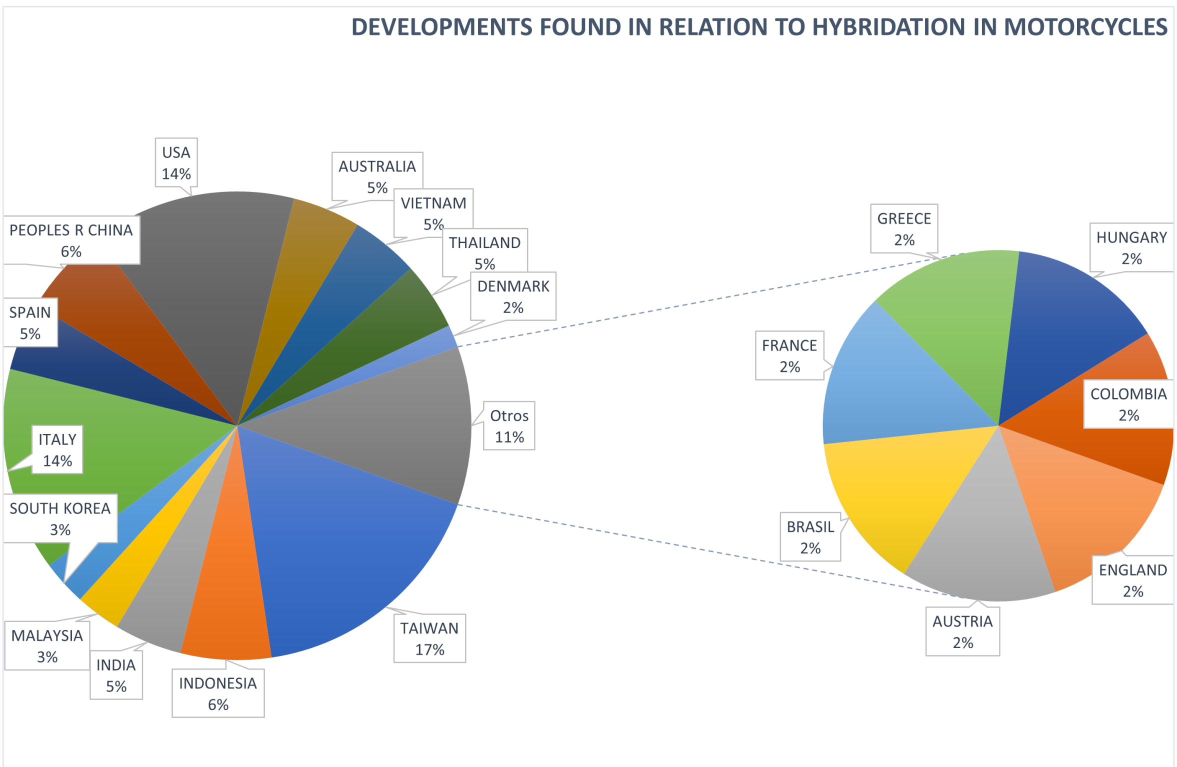


Figure 2.1: Study and analysis of articles found

It is evident that countries with the highest percentage are those that are considered the largest producers of motorized two-wheeled vehicles, such as: Taiwan, Italy, and USA.

According to statistics of PONT group (8 20), more than 80% of the world's motorized two-wheelers are sold in Asia, with low-displacement engines being the most popular. Segmenting the market according to the percentage of sales in the world, scooters up to 50 cc comprise 18%, scooters over 50 cc comprise 29%, motorized two-wheelers over 50 cc comprise 48%, and electric motorcycles comprise the remaining 5%. In China, 60% of citizens own a motorcycle, in India 47%, in Pakistan 43%, in the Philippines 32%, and in Japan 21%, while in Latin America, Brazil is the country with the most motorcycles per inhabitant, with 29%. It is followed by Argentina with 24%, Colombia with 23%, Bolivia with 22%, Nicaragua with 17% and Venezuela with 16%. In Europe, the country with the highest number of motorcycle owners is Italy, with 26%, followed by Greece, with 23%.

Table 2.2 summarizes the articles analyzed for this project.

Name	Motorcycle reference	Config.[a]	Transmiss.[b]	Coupling	Location	General modifications	Added parts	Batteries	Methodology
Chi-Chang and Jwo (2007)	50 cc Tact of Sang-Yang Motorcycle Company	P	CVT	Two-axis coupling.	Electric motor on the rear wheel.	The motor gearbox is attached to the rear wheel. Change gearbox (# of teeth).	Tamagawa-Seiki servomotor 500 W (3600 rpm/75 V).	Rechargeable lead-acid battery	Not Defined
Hazarathaiah et al. (2019)	Boxer bajaj	P	Mech	Direct to sprocket	Electric motor on the rear wheel.	A chain sprocket is mounted in place of the disc brake.	HUB Motor 800W y 48V	1 lithium-ion battery with a power of 48V and 12A.	Not Defined
Rangan et al. (2017)	Street without reference	P	Mech	Direct to sprocket	HUB type electric motor on the rear wheel.	DYNAMO	HUB Motor	NIA	Not Defined
Hsu and Lu (2010)	Four-cylinder 125 c.c. gasoline engine manufactured by Yamaha.	P	CVT	Electromagnetic clutch, pulleys and belts.	Central electric motor	The electric motor is inserted under the saddle.	TECO motor 24 V DC, 1 kW.	NIA	Not Defined
Sheu and Hsu (2006)	Scooter de 125 cc	P	CVT	2 one-way clutches and CVT rubber V-belt.	Central electric motor	TEST BENCH	DC electric motor 0.8 kW.	NIA	Not Defined
Mahendran et al. (2019)	Motorcycle TVS 50cc	P	CVT	Each individual	HUB type electric motor on the rear wheel.	None	60V BLDC HUB motor of 350W.	(10.4A) Ion-Litio	Not Defined
Asaei and Habibidoost (2013)	Scooter 125 cc	P	CVT	Each individual	Electric motor type HUB front wheel	None	500 W BLDC electric motor.	NIA	Not Defined
Wu et al. (2013)	Scooter Sanyang of 150 cc	S	CVT	Cinematic chain	Electric motor type HUB front wheel	CVT is eliminated, there is no mechanical mechanical coupling between the engine and the powertrain.	Generator, EVT 900W HUB motor.	4 YUASA REC22-12 lead batteries with a nominal voltage of 12V and a nominal capacity of 22 Ah.	Not Defined
Kannan et al. (2020)	Scooter	P	CVT	Each individual	Electric motor type HUB front wheel	None	NIA	NIA	Not Defined
Po-Tuan et al. (2019)	Grand Dink 150 cc	P	CVT	An epicyclic gear train decelerator assembly with a speed reduction ratio of 2.3 was designed and connected directly to the motor shaft.	Central electric motor	Replacement of the throttle with an electronic one.	TAIGENE 3-kW DC, 48 V.	32 lithium-ion batteries Each cell 3.3 V/10 Ah.	Not Defined
Shenghani et al. (2017)	Motor GenSat of 127cc	P	CVT	Two chains, one for each motor.	Central electric motor	TEST BENCH	DC electric motor of 24V and 120A.	NIA	Not Defined
Polanía-Restrepo et al. (2020)	NKD 125 cc	P	Mech	Each individual	Electric motor type HUB front wheel	Saddlebag holder for battery holder.	HUB Motor 3000W	48V 10Ah LiFePO4	VDI guideline
Utama and Didi (2015)	NIA	P	Mech	NIA	HUB type electric motor on the rear wheel.	NIA	NIA	NIA	4 own stages
Koslowsky et al. (2003)	Scooter Honda GX31 31 cc ICE.	P	CVT	Planetary gears.	NIA	TEST BENCH	LEMCO LEM-130 for 36 V	Lithium-ion GENESIS modified for 36V 60Ah	Not Defined
Morandin et al. (2014)	Aprilia RS4 125 cc	S	Mech	Direct to combustion engine	Central electric motor	None	Electric motor	NiMH 450V battery	Not Defined

Table 2.2: Summary table of articles

[a] "P" is Parallel, "S" is Series, [b] "Mech." is Mechanics, "CVT" is Continuous Variable Transmission

It is observed that 86.66% of the articles used the parallel configuration and 13.33% the series configuration, also 66.66% of the conversion projects were in a CVT transmission motorcycle and 33.33% in mechanical transmission. In addition, 33.33% used a central Electric Motor (EM), and the same percentage used a HUB type EM in the rear wheel, while 26.66% used a HUB type EM in the front wheel, and 6.68% of the articles do not present information about the EM used. Also, 80% of the projects were motorcycle conversions and 20% were designs of couplings for motorcycle conversions but only tested on test benches or simulations.

Only 2 articles mention a methodology, which is equivalent to 12.5% and 87.5%. Utama and Didi (2015) defined a methodology of 4 stages, where a physical model, a finite element model, and a theoretical model, where the functional analysis is performed, were established, and, finally, there is a post process, where the results are observed. Polanía-Restrepo et al. (2020) used a VDI methodology, dealing with the steps for the design of mechatronic systems, consisting of 3 stages.

2.2 Methodologies

This section shows the analysis of the existing design, redesign and standardization methodologies, where the advantages, disadvantages, recommended tools, specific applications, among others, are obtained. These are the ones directly related to the proposed objective.

2.2.1 Design methodologies

2.2.1.1 Design thinking

It is defined as a methodology focused on applying critical and creative thinking to understand, visualize and describe complex and ill-structured problems, in order to develop approaches to solve them. While the focus is primarily on the problem and the product, the model uses customer feedback to solve ill-structured problems, according to Clark (5 13).

Its steps are presented in the Figure 2.2: Apply critical thinking to understand the problem, Observe to understand the operating environment, solve the right problem by defining it, ideate, imagine or devise solutions to solve the problem, adapt to dynamic conditions by prototyping, and, achieve the designated objectives.

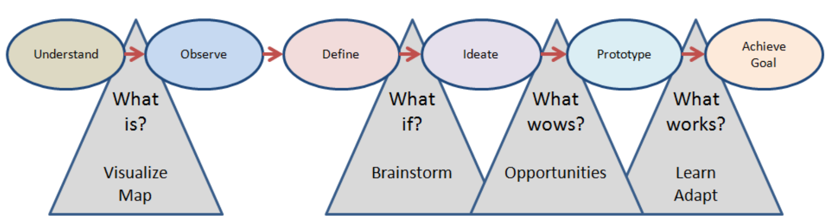


Figure 2.2: Sequential structure of design thinking by Clark (5 13)

2.2.1.2 Agile design

It is a methodology that divides tasks into small increments with minimal planning that does not directly imply long-term planning. Iterations are short periods of time that usually last from one to four weeks, collaboration and small but quick iterations make it possible to maintain agility that adapts to a changing environment. It also focuses on customers being part of the team to be able to adapt to rapidly changing requirements, these customers must have the knowledge to be collaborators in the design of the product Clark (5 13).

Its structure or methodological process is described in the Figure 2.3: Selecting the project and developing the vision, initiating the project by obtaining stakeholder buy-in, funding and building a team, delivering small iterations of work that meet the changing needs of the stakeholders, Release End Game (delivering the final package), production, operating, maintaining and supporting the system, and, finally, the retirement stage, removing when no longer needed.

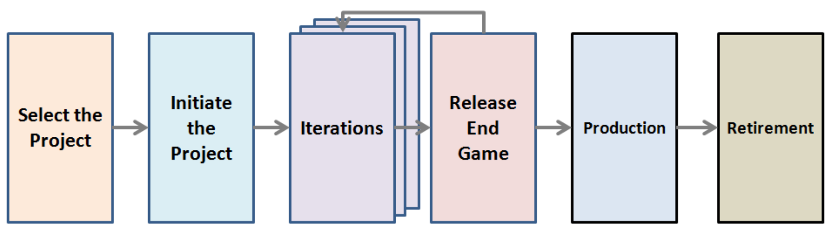


Figure 2.3: Sequential structure of agile design, by Clark (5 13)

2.2.1.3 Problem X

This methodology is used to solve complex or wicked problems for 21st century challenges that defy conventional planning, using extreme adaptive approaches to innovate by solving complex problems, i.e. a problem that leads to a solution that brings more new problems to be solved; the problem and its solution cannot be easily grasped by customers, designers or experts. Therefore, when new knowledge is discovered, a design or "test" solution is attempted to determine if it is viable (called a "design iteration"). This process is repeated until sufficient viable solutions exist and the problem has been reduced to a desirable state Clark (5 13).

Its methodological structure is given the steps presented in the Figure 2.4: Immersion: immerse yourself in the problem to gather customer insights and gain empathy. Convergence: bring all things together, such as physical, technology, software and services into a logical design. Divergence: explore new advantages. Unlike agile design, which uses mainly version iterations, problem X uses mainly design iterations done to test a method, function, feature, etc., and, finally, the adaptation stage: which tries to stay agile in a fast moving environment by going in new directions when facing obstacles.

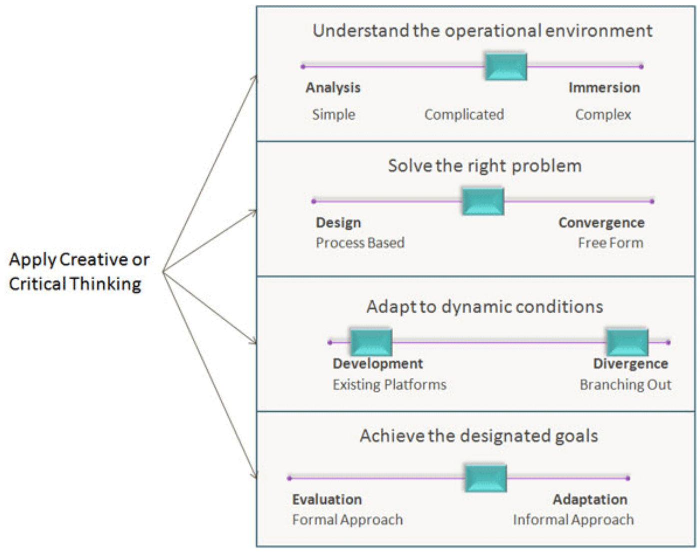


Figure 2.4: Sequential structure of Problem X, by Clark (5 13)

2.2.1.4 Lean methodology

This focuses on working in a "smarter" way, dividing the project into parts where the whole process is divided into cycles, and, at the end of each cycle, a minimum viable product (MVP) is launched to the market. Lean methodology is function-oriented and is sequential and incremental at the same time.

The advantages of this methodology is that the product is released to the market and creates a feedback base from this version, considered in the next version, where improvements are made and features are added according to user needs. The best time to use the Lean methodology is when all 3 parties can work together at the same time, i.e. client, designer and analyst Srivastava (0 16).

2.2.1.5 Fancy Design Sprint Methodology

This methodology consists of a research process to test if there is a real market need for your project, followed by the design and development phase, using design thinking methodology to help validate ideas, solve product challenges, align the team's vision of a product, and, at the same time, set goals and objectives. A sprint is a time set according to the project during which the design challenge (the goal, the problem to solve) is solved, solutions are generated, the prototype is built and verified with the target users Maria. (5 07).

Reached conclusions are the basis of the final solution that will be tested again in the real world. Its steps are discover, draw, decide, prototype, and test. If there is no testing phase, it is not a Design Sprint.

2.2.2 Redesign methodologies

According to Van Eldonk et al. (1996), redesign is defined as a design process applied to an existing product or to a prototype or detailed concept. This process uses a variety of techniques that can be models, graphics, diagrams, guidelines, etc. in order to analyze and fully understand a product. They established a process based on four stages: diagnosis (definition of which parts of the design can remain the same and which must change); re-specification (definition of new specifications of the parts to be changed); design (common stage of design to meet the specifications), and, finally, the stage of evaluation of the new design.

Lefever and Wood (1996) mentioned that in the redesign of products, a new product is a variation of a previous product. It is not common to start the design from scratch, because companies make use of previous experiences to develop products that include functions and improvements. This requires a process of research and development, not only for the product but also for manufacturing processes.

2.2.2.1 Production-oriented product redesign methodology

Escoto and López Parra (2019) stated that most of the structured methodologies to carry out a redesign process, seek to renew the products from a particular approach, such as: assembly, manufacturing, production, among others. For this reason, they defined a methodology for product redesign oriented to production, which is composed of 4 stages prior to a redesign process, and 7 additional stages directly related to this process, as it is presented in the Figure 2.5.

Figure 2.5: Sequential structure of production-oriented product redesign methodology by (Escoto and López Parra, 2019)

They concluded that the development and implementation of methodologies for design or redesign of products based on new technologies, increase the probability of technologies, the likelihood of market alignment and market, and the knowledge and technology transfer to the industrial sector.

2.2.2.2 ACI redesign methodology

The redesign methodologies exist to perform improvement and innovation processes. These methodologies are based on evidence and set tools to ensure the sustainability and integrity of the systems. The ACI redesign methodology is composed of 5 phases, presented in the Figure 2.6: The initiation phase, where the opportunity is explored, people are involved, and the approach is planned. The diagnostic phase is completed with data capture, data analysis. Solutions stage, where ideas are generated, selected and analyzed. In the Implementation stage the operational management and implementation are carried out. Finally, in the sustainability stage, the sustainability of the approach is analyzed, and the results are evaluated and disseminated..

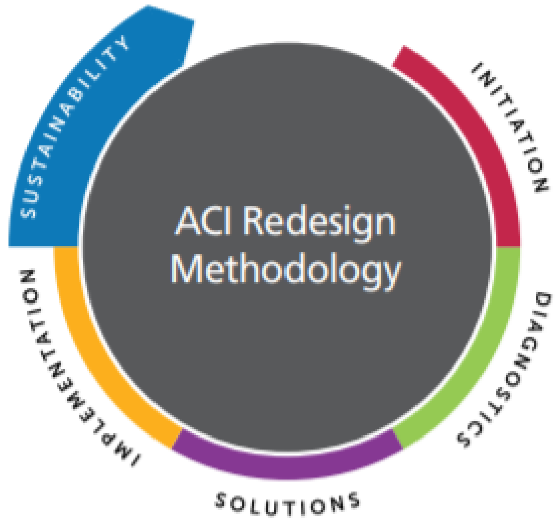


Figure 2.6: Sequential structure of ACI methodology, by NSW government (0 11)

2.2.2.3 Redesign methodology for mechanical assembly

The methodology follows a linear flow. Structured data collection is the first step, followed by knowledge generation leading to solution generation and implementation. The first two stages of the flow are knowledge creation. Once the knowledge is generated, solution generation becomes the goal.The objective of this methodology is not to generate solutions, but rather to highlight where the assembly project can be redesigned.

The approach taken by this methodology is to allow engineers to apply their own ingenuity and creativity in the search for solutions. These should be created through uncontrolled innovation, but the selection and approval process plays a key role in the evolution of a project El-Nounu et al. (2017).

2.2.2.4 Methodology for the design and redesign of processes

According to Valero et al. (2006), in order to design a methodology, 8 main steps must be taken into account:

1. You must create a new process taking into consideration and respecting, as much as possible and necessary, the characteristics of the previous processes.
2. It must identify the distinct and common activities of the processes to be combined.
3. It should contemplate the choice of a common modeling language, technique or tool to facilitate the comparison of the processes.
4. It must identify from among the distinct activities, those whose execution characteristics cannot be altered, since they constitute restrictions for the final creation procedure.

5. It should take into account whether the result is appropriate for each of the parties involved.

6. It must define and allocate, where appropriate, responsibility for the performance characteristics of each activity.

7. It should be general enough to help in all possible scenarios.

8. It should seek synergies in the combination of processes.

With these steps, they proposed the design and redesign methodology, with 5 phases presented in the Figure 2.7, where 5 questions are asked. The first phase deals with the current situation, while 2, 3 and 4 deals with the future situation, and, finally, 5 is the result of the process of fulfilling the objective. The focus of this methodology is to combine two or more processes into one from the general to the particular, as is the objective of this research in which it seeks to obtain a methodology that combines the process of design, redesign, and standardization.

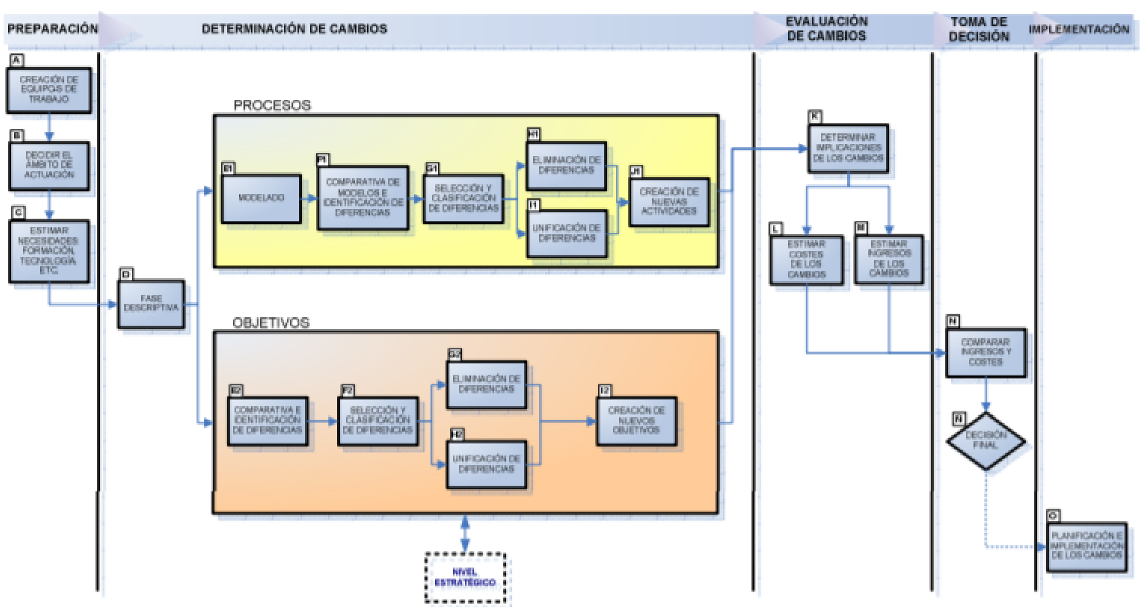


Figure 2.7: Sequential structure of the methodology for the design and redesign of processes, by Valero et al. (2006)

2.2.3 Standardization methodology and modular design of components

Standardization aims to increase the efficiency of a process, eliminating all unnecessary activities, according to a logical sequence, which keeps the task as simple as possible and ensures the fulfillment of an objective. The standardization of things refers to the fact that objects must be the same, while modularity, According to Gershenson et al. (2003), facilitates the standardization of components and increases the variety of products. In addition, modularity influences the rationalization of product lines and the diversity of products at low cost.

2.2.3.1 DFV methodology

Martin and Ishii (2000) developed a method to guide the redesign of products and increase modularity and at the same time standardization. Based on the concepts of Ulrich et al. (1998), they proposed 2 types of product architectures: spatial, which is defined as the set of product types that a company offers to the market at a certain point in time, in order to meet the needs of different market segments, and, the generational, when a product is updated after a period of time.

With these concepts in mind, Martin and Ishii (2000) proposed a methodology for variety, based on quantifying the rates of change and guiding the redesign of a product. It consists of 11 stages, comprising comparative studies and tools such as QFD, as it is presented in the Figure 2.8.

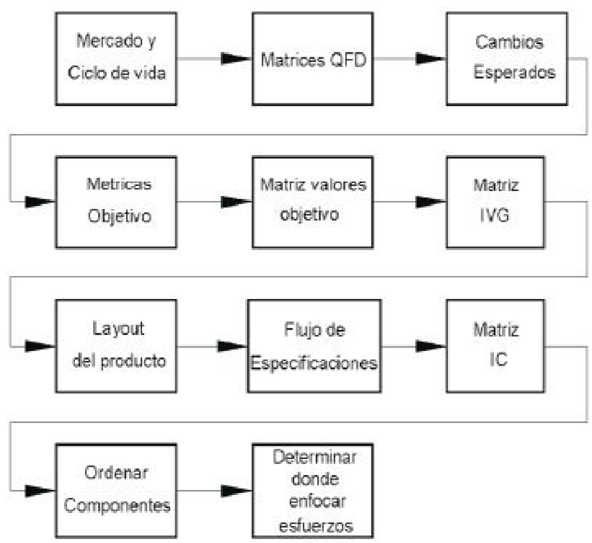


Figure 2.8: Sequential structure of DFV methodology by Martin and Ishii (2000)

2.2.3.2 GAs-DSM methodology

This methodology is designed for architectures and product families. It uses the optimization of modules or cluster, established from the individual product to the specific product market, that is, the market segment. Through the clusters, the representative characteristics of the product and the changes between product families are found, in order to observe the fulfillment of the needs or requirements of a client, and to be able to make an evaluation and optimize the general structure of a product. This methodology is composed of 11 phases, as it is presented in the Figure 2.9, obtaining as a result the modularity, standardization, community and reusability of a product idea Zha and

Sriram (2006).

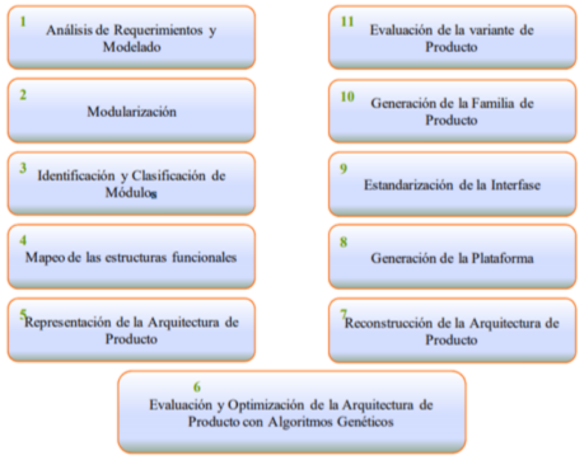


Figure 2.9: Sequential structure of DSM methodology, by Zha and Sriram (2006)

2.2.3.3 Product Platform Concept Exploration Method (PPCEM)

Simpson et al. (2001) established a systematic design methodology with respect to product families, but specialized in the functional part and the manufacturing process. It consists of 5 steps, as it is presented in the Figure 2.10, and its purpose is to facilitate the design of a product family based on scalability.

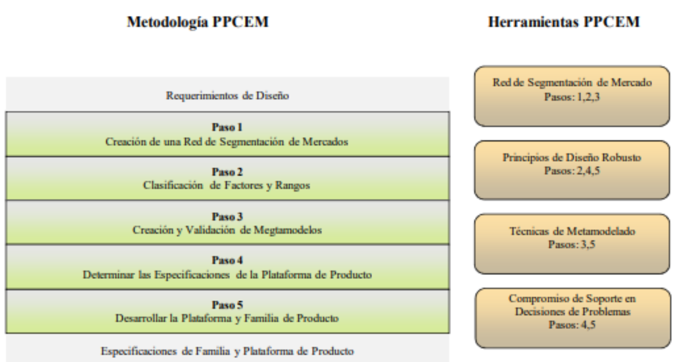


Figure 2.10: Sequential structure of PPCEM methodology by Simpson et al. (2001)

Of all the methodologies analyzed, none of them combines the three processes that are the objective of this research, which are: design, redesign and standardization. All methodologies have stages of requirements approach, generation of solutions and evaluation. These are the characteristic phases of a design methodology. About the redesign methodologies, it is evidenced as main characteristic the part of the cyclic phases, that is to say, that processes of iterations in several stages are carried out. Also, a characteristic stage is a market analysis of the specific product, where the direct competition, previous studies of the product, and the application segment are found. Finally, from the standardization methodologies, it is observed that when the family is defined, it is characterized in order to find similarities and variations among the family.

2.3 Hybrid motorcycles from major manufacturers.

Asian companies cover the hybrid motorcycle market today, as they are the largest manufacturers of this mode of transportation. Yamaha was the first to announce the Gen Ryu in 2005, and over the next decade numerous patents were filed by Honda, Kawasaki and Suzuki. Also, in 2010, Italian brand Piaggio announced its 3-wheel hybrid scooter model Jimenez (5 09). Honda announced its Honda-PCX hybrid scooter, in 2018, as a powerful low-emission, fuel-efficient motorcycle, composed of a 125 cc 4-stroke engine, and an electric motor. Honda also presented the Furion M1, a high-displacement motorcycle (650 cc) with 180 hp power from its heat engine and an electric motor.

The development of hybrid two-wheeled motorized vehicles has also been a reason for the union of major brands, such as the TVS Zeppelin concept, the result of the union of the Asian brand TVS with BWM. 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 two-wheeled motorized vehicles demonstrates the impact and interest of the market for this type of vehicle. However, all of these products are developed from scratch, and conversion kits or engine modification kits for existing vehicles on the market today are still a value proposition to enter this segment. In addition, to these modifications being standardizable to the entire segment, the most recent announcement of the patent of a hybrid two-wheeled vehicle is from Kawasaki with a dyno, first the electric motor comes into operation, which for a few moments turns the drive wheel, and then gives way to the heat engine, of what is shown in the announcement is that it will be a motorcycle of low displacement and for urban cycles.

These are the first developments of modifications, changes or additions in the motorization of a two-wheeled vehicle, being companies with great influence in the market of these vehicles. Most of the information is confidential as: the times, the design methodology, test protocols for the development of new products, also patents are not yet public. There is no motorized two-wheeled vehicle with modification in the motorization in the market, and any of the references mentioned are commercial.

2.4 Converted hybrid bikes and prototypes

The following is an analysis of the different studies and developments that have been implemented in the conversion processes in two-wheel vehicles with automatic transmission and mechanical transmission. The classification considers the transmissions to conclude in which of the two have been carried out more developments and to relate the reasons. Also, the methodologies or design protocols used in the development of the prototypes have been emphasized.

Of the 3 topologies, the most used is the parallel, because it has advantages in all aspects, emissions, autonomy, dimensions, implementation among others. While the series topology, having direct connection to the ICE, represents greater intervention in the originality of the vehicles, and depending on the need, more powerful engines are required, implying more costs for the process. Also, the combination of both although it is the union of all the advantages is also of the disadvantages, becoming a more complicated application in hybridization. The Tables 2.3 and 2.4 present a comparison of advantages and disadvantages of hybridization processes according to the type of transmission used.

CVT Transmission	
Advantages	**Disadvantages**
Improved overall energy efficiency.	Only possible for light motorcycles with relatively small engines.
Uses a single electric motor/generator.	It has a torque and power limiter.
Fewer parts for coupling system between motors.	Complex gear ratio modification.
Less efficiency losses between mechanical systems.	
Small footprint on the motorcycle.	
Little intervention to the originality of the motorcycle.	
Easy interaction with the control unit.	

Table 2.3: CVT transmission comparison chart.

Mechanical Transmission	
Advantages	**Disadvantages**
They are the largest percentage of motorcycles in the world.	Increased volume occupied in the powertrain.
Easy maintenance.	Greater number of modifications for the adaptation of any system.
Longer service life.	Unique designs per motorcycle reference.
	Difficult communication with the control unit.

Table 2.4: Mechanical transmission comparison chart

When comparing both transmissions, it is evident that using a CVT transmission in a hybridization process presents more advantages than in a mechanical one, since it presents fewer technical, mechanical, dimensional and efficiency challenges, among others. It also reaffirms why most of the research and prototypes have been carried out with this type of transmission.

2.4.1 Automatic or Scooter type

Having a Continuously Variable Transmission (CVT) instead of a fixed-pitch transmission allows the most efficient operating points for the combustion engine at given torque demands to be chosen freely and continuously.

Sheu and Hsu (2006) featured a mechanical type rubber V-belt, a continuously variable transmission (CVT) and chain drives to realize the hybrid power system, a scooter type motorcycle and a DC 0.8KW electric motor located in the central part of the chassis. They carried out tests in the prototype in a static way with a test bench.

A parallel hybrid system is proposed, consisting of a gasoline engine, an electric motor, a transmission, a power inverter, and an electronic controller.

The transmission connects the ICE and the rear wheel of the motorcycle. This is composed of CVT with a shoe-type clutch, on the other side two chain transmissions with two one-way clutches and a final drive connects the EM.

To maximize performance and reduce emissions, the parallel configuration is used. This transmission can operate in four different modes: electric motor mode, motor mode, motor/charging mode, and power mode.

The advantages of the this hybrid system are:

- Using a single electric motor/generator
- Changing the operating mode through mechanical type clutches for easy and low-cost control.
- Using a CVT system and electric motor/generator to control the operating range and the motor output torque, improvin overall energy efficiency.

The results of the functional tests allowed to conclude that the hybrid-electric transmission system for motorcycles is practicable and that it presents advantages over other designs.

Another case of this type of transmission implemented in motorcycles is that of Hsu and Lu (2010) in which a successful implementation of a hybrid system is presented using an electronic control unit (ECU) to integrate two subsystems, one being the 125cc ICE system manufactured by Yamaha, and, the other, a TECO 24 V DC, 1 KW electric motor. A CVT was combined, where the EM is used as the primary power source in the low-speed operation cycle. It varies to work with the gasoline engine in the medium- and high-speed operation cycle, meanwhile, the battery system is continuously recharged at the same time.

For power transmission, along with the CVT, an additional sprocket gear and chain pulley mounted on the gearbox was implemented together with the actual 125 cc gasoline engine, as it is shown in the Figure 2.11, where the one-way clutch is C1, the pulley device is B1, and the final drive is G1. C2 is the electromagnetic clutch, and A1 is the belt system.

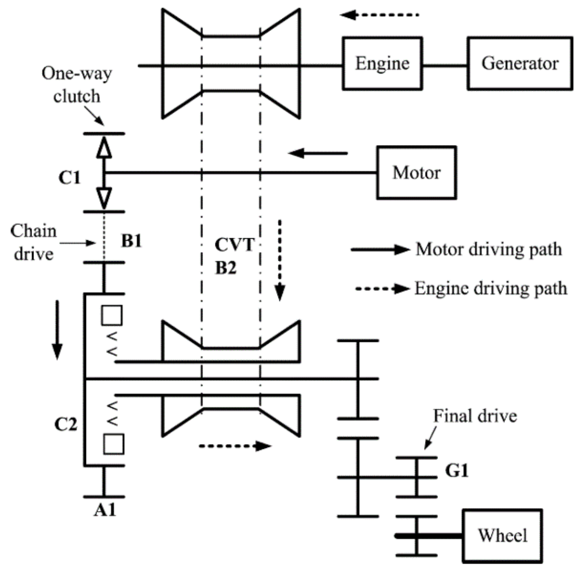


Figure 2.11: Prototype for Hsu and Lu (2010)

The experimental results allowed to conclude that the engine shutdown time is approximately 47.5% of the total running time, which translates to exhaust emissions reduction, and also shows that the hybrid mode effectively consumes between 14-24% less fuel than the consumption in gasoline engine mode.

The prototype presented by Asaei and Habibidoost (2013) started from a 125cc scooter-type motorcycle, a brushless direct current (BLDC) motor mounted on the front wheel, and an ICE connected through a CVT to the rear wheel, which for a hybrid power transmission can operate in automatic driving mode and has high efficiency.

The motorcycle contains a hub type engine in the front wheel, in order to save fuel consumption when reaching a certain distance traveled at high speed. Also on the rear wheel, it features a dynamo type, which helps to extract data from the regenerative electric power system.

With this, the electric motor is used to move the motorcycle at speeds below 15 km/h, and from this speed, the combustion engine is in charge of moving the motorcycle. This is because at low speeds the ICE is inefficient and at high speeds the EM does not have enough power. It is concluded that it would be ideal to have a smaller ICE and a larger EM which could lead to better results.

A simulation of the motorcycle with only the ICE and in hybrid mode, in two different driving cycles, one similar to urban traffic (ECE) and the other to highway traffic (CYC/ARTERIAL), is carried out. It is concluded that if the motorcycle is to be used in urban environments, with many moments in continuous acceleration and deceleration and few moments at constant speed, the energy savings and emissions reduction will be considerable, on the contrary, for highway use for long periods of time, the change would not be justified.

In a test cycle the hybrid mode shows that the engine shutdown time is about 47.5% of the total running time, indicating that the hybrid mode actually consumes less fuel than ICE-only mode. This can achieve the objectives of effectively reducing the amount of pollutant emissions and maximizing the performance of the hybrid system, remembering that the driving modes in the parallel configuration are ICE, EM and the combination of the two.

On the other hand, Po-Tuan et al. (2019) through a patent, promoted the design of a power divider featuring 2 inputs and one output, which can generate independent or related functions, as it is presented in the Figure 2.12. They made a GRAND DINK 150 cc motorcycle with CVT transmission and a TAIGENE 3-kW DC 48 V electric motor located in the central part of the chassis, and for its transmission they designed a set of epicyclic gear train decelerators with a speed reduction ratio of 2.3 and connected directly to the motor shaft, with a parallel configuration.

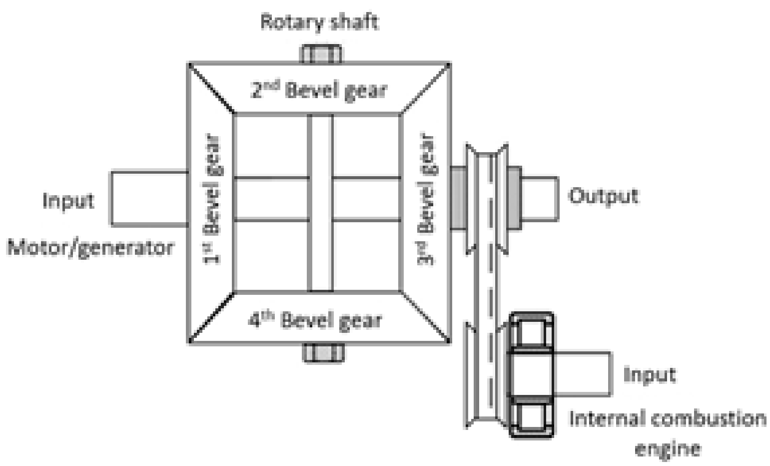


Figure 2.12: Prototype for Po-Tuan et al. (2019)

When the system requires low power, it can be driven only with the EM, and when the load demand exceeds the power delivered by the EM or it is driven at high speed, it recognizes that the output power cannot meet the actual power needs, and the vehicle therefore proceeds to switch to the ICE mode, which works in an optimal operating range. But if the EM power is increased, it can compensate the ICE output power. It is established that the system, when operating with respect to low demand, can only be driven by the EM, then when distributed by this mechanism, the output torque of the power transmission is doubled and the output shaft speed is half the ICE speed.

Finally, the power mode switching control strategies in the hybrid electric motorcycle are mentioned, which start from three modes: the EM drive mode in which it is operated at low power, in which it is only used to drive and provide power; the ICE generator/drive mode which is used when the driving load exceeds the engine power; and, the dual power transmission mode is used at high speed or heavy load, in which the EM power is added to compensate for the insufficient power output of the ICE.

Using parallel topology, Chi-Chang and Jwo (2007) recreated a regenerative hybrid system on a 50cc Tact motorcycle, from Sang-Yang Motorcycle Company, in order to match a 100cc motorcycle to be taken as a model. As it is a scooter type motorcycle and with CVT, it is intended to be one of the main means of transportation in its city.

They modified the structure of the conventional transmission, as it is presented in the Figure 2.13, providing a torque difference of 0.43 kg under a voltage of 20V in order to reach a top speed of 90-100 km/h, adding a Tamagawa-Seiki servomotor of 500 W (3600 rpm/75 V) on the rear wheel. The precondition for these two different types of power to work together is that the rotational speed of the rear wheel and that of the electric motor must match. Starting from rest there is a gearbox system that avoids reversing the power transmission, so that the EM behaves as an unexpected load when the motor speed is lower than the wheel speed.

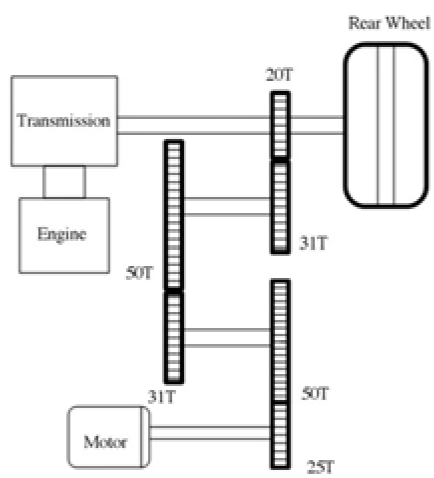


Figure 2.13: Scheme of the parallel hybrid system for implementation proposed by Chi-Chang and Jwo (2007)

They featured a single-axle parallel drive and two axles projecting to the rear tire. It is assured that the hybrid prototype operates correctly and safely, showing overall efficiency increase of 35%. It should be noted that this prototype is not connectable to the grid for recharging, but it is the combustion engine itself that recharges the batteries.

Wu et al. (2013) exposed a prototype hybrid motorcycle implementing an engine generator, EVT 900W HUB type, located on the front wheel.of a Sanyang 150cc. scooter type motorcycle with CVT transmission in series configuration, as it is presented in the Figure 2.14.

Figure 2.14: Generator included in the prototype by Wu et al. (2013)

It is claimed that the developed prototype has good functionality as it can switch from electric to ICE-only mode very smoothly and works stably.

When the vehicle enters regenerative mode, it reaches an average of 3500 rpm, with a BSFC (Brake Specific Fuel Consumption) of less than 250 g/kWh. Overall, the motorcycle's fuel economy for city driving increased from 30.8 km/L to 73.7 km/L, an improvement of 139%.

Authors stated that the current prototype still has potential for improvement and that implementing another (parallel) configuration will improve fuel economy, . In the future, a method to automatically switch to ICE mode will be further developed. In addition, implementing an SOC (State Of Charge) estimation scheme combined with engine start control will make the powertrain more intelligent and efficient.

Kannan et al. (2020) proposed a conversion of a scooter type motorcycle. Regarding the kinematic chain, they performed a distribution of the mechanical propulsion in the following way: in the front wheel there is a HUB motor, in this case it will be of BLDC type, from there, its control is focused through a throttle on the handlebar controls. On the other hand, there is the transmission in the rear wheel with the ICE motor and a CVT transmission. The authors claim that when the bike operates in both modes, maximum efficiency is achieved, as more of the combustion power is utilized.

By achieving synchronization of these two types of engines, it is possible to tailor the different methods of power that can be delivered both on open terrain and on slopes. While with an EM approximately 75 km can be covered on a single charge, and with an ICE, one liter can reach 50 km, the combination of both achieves approximately 150 km, something that benefits urban traffic, as well as the reduction of pollution that can be generated by being ICE only.

Shenghani et al. (2017) proposed a parallel hybrid system with a 127cc GenSat scooter engine for hybridization. The method of mechanical traction is with two chains, one for each engine, as it is shown in the Figure 2.15, to generate the desired traction. This was not implemented on a concrete bike, but on a test bench setup.

Figure 2.15: Development of Hybrid Two-Wheeler Vehicle by Shenghani et al. (2017)

It can be demonstrated that the system could be electrically operated. The vehicle autonomy system has been improved and through a test bench it is possible to demonstrate the different torques that the rim will be subjected to for a scooter. Although it is a servo motor, it requires constant manipulation by the user to be plugged in and maintain its charge, this helps to prolong the life of the batteries. In the results obtained, the efficiency of the prototype is increased by manually changing the EM and ICE at the lowest RPM, while with an autonomous system the RPM increases by 300%, but with the complexity and the problem of maintaining the battery saving.

Finally, Koslowsky et al. (2003) proposed a test bench that starts from the definition of a kinematic chain based on the following configuration: ICE Scooter Honda GX31 of 31 cc, EM LEMCO LEM-130 of 36 V generator, and, finally, the dynamometer.

Initially, it is stated that the ICE is the one that provides the mechanical energy necessary to move the generator. This generator, through an interface formed by wheels and a toothed belt, is adapted to convert this mechanical energy into electrical transmission to the controller and the respective batteries.

Passing through the controller, it sends the energy to the EM which finally converts the electrical energy into mechanical energy. This mechanical energy production gives the final traction to the hybrid motorcycle model. The main objectives proposed are to minimize the powertrain space requirement (volumetric), to maximize the power-to-weight ratio, to maximize the efficiency and response of the integrated system, and to make the best use of the available resources and allocated funds.

It is proposed to connect a pinion to provide the ICE power, with a parallel system to achieve higher engine torque, and to send the power from the combustion engine directly to the drive wheel.

One of the main objectives was achieved, which was a constant and continuous cruising speed of 40 mph with a required EM power of 1.2kW. On the other hand, the ICE run with the generator, where a maximum power of 0.562 kW is obtained. In addition, to setting a target of achieving acceleration from 0 to 35 mph in 8 seconds, required an average power that was not possible to achieve (approximately

2.6kW).

2.4.2 Mechanics type

Zhang et al. (2009) discussed three typical types of basic coupling units applied in hybrid electric vehicles including fixed shaft drive mechanism, planetary gear, and a floating stator electric machine.

According to the mathematical relationship between the input and output parameters of the coupling unit, there are two different coupling effects: torque coupling and speed coupling, according to this the type of coupling mechanism is chosen.

In the fixed shaft transmission mechanism, the ICE and the EM are coupled by the fixed shaft transmission mechanism, for example pairs of gears. This basic unit of coupling has one degree of freedom (DOF). In planetary gear sets the motor and the electric machine are connected to the carrier and the sun gear respectively, while the ring acts as the output end. In the electric stator machine, the rotor of the electric motor connects to the motor and the floating rotor acts as the end output. Unlike the conventional electrical machine, the floating stator can rotate freely around the rotor axis. Figure 2.16 presents these three types of basic coupling units.

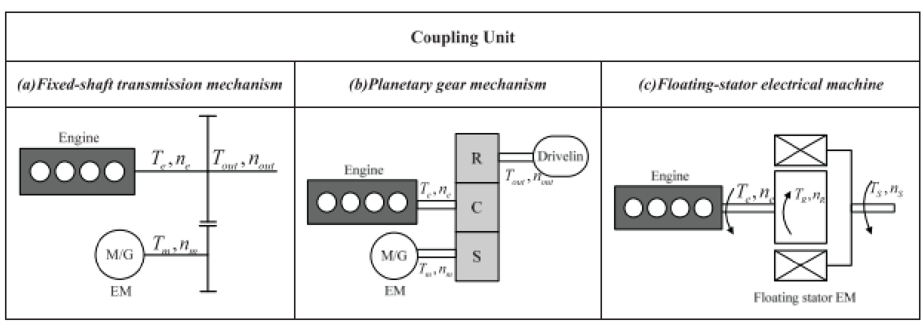


Figure 2.16: Prototype for Zhang et al. (2009)

The feasibility and conceptualization of the electromechanical coupling system in a hybrid is determinant for the continuous operation of the vehicle, so although a theoretical approach is generated by Zhang et al. (2009), the results obtained are not determinant because it is a work focused more on the idea of examining the performance of these composite systems that are present in the industry as the Toyota THS, the Bosch Dual-E transmission and the dual-rotor electric machine.

Utama and Didi (2015) stipulated the design of a wheel hub and wheel drive cover using the finite element method in simulation software, through the design and implementation of a hybrid system on mechanically driven motorcycles, consisting of ICE and an EM coupled to the rear wheel, as it is shown in the Figure 2.17.

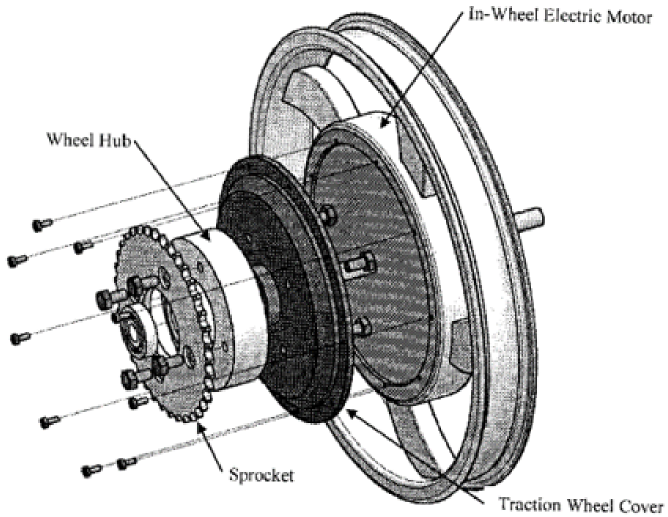


Figure 2.17: Prototype for Utama and Didi (2015)

The EM is DC type with 48V and static rotation speed up to 527 rpm, and the ICE is from a scooter, so the purpose of the wheel hub was to connect and transfer the torque of the motorcycle by means of the factory designed component sprocket drive system (this protects the electric motor splashing water, dust, dirt, etc.), and the drive wheel cover. Both components must be tested to ensure sufficient strength to withstand the load of the sprocket and motor.

Static linear type simulation has been used in this study, since the loads were assumed as well as the material used, according to the stress-strain diagram of the material. To perform the CAD analysis, restraint constraints are imposed on the surface of the drive wheel cover connected to the motor housing by bolts. No strength tests were performed, only functional and dimensional.

Mahendran et al. (2019) developed a new design for two-wheel drive hybrid motorcycles, including electric front-wheel drive and rear-wheel drive with conventional ICE. The electric front-wheel drive includes a brushless hub EM, sine wave controller and battery, and the rear-wheel drive consists of a two-stroke ICE connected to the rear wheels by a chain. Furthermore, a suitable control circuit has been designed to switch between electric drive and ICE drive when necessary.

The battery and the control system are located in the lower part of the saddle, which are connected to the controller, which is located on the handlebar controls, determining the operation of the Hub-type motor of the front wheel.

Due to a certain information of average distances traveled by a citizen in India, targets are defined to design the motorcycle, for example, when starting from idle, it should generate an electric propulsion of at least 10Km using a BDLC motor of 60V and 350W; subsequently, it continues to run much longer with the ICE.

Rear wheel propulsion is provided by a traditional two-stroke ICE with 50cc; the ICE drive is only used for long, high-speed journeys, while for shorter trips, the vehicle is electrically driven, the electric propulsion is powered by a 60V, 350W hub EM. This provides a range of approximately 25 kilometers.

Rangan et al. (2017) proposed a hybrid prototype where the motorcycle works initially with ICE as a source of energy that drives the vehicle, and with a dynamo that converts mechanical energy into electrical energy. This dynamo is connected to the drive chain that connects the ICE and the rear wheel and also to the battery, where it stores all the energy supplied by the ICE. Once the battery is fully charged, the fuel supply to the ICE stops, and then, the EM drives the vehicle and the speed of the vehicle is controlled by a rheostat. Once the battery is depleted, fuel is again supplied to the engine and the engine runs the vehicle and the process continues.

Therefore, a physical model is proposed that can be applied to the operation of the powertrain in series because having the implementation of a dynamo that collects all the mechanical energy and converts it into electrical energy. It can be consequently connected to the ICE, and it works in parallel because when the battery receives the maximum amount of energy supplied by the dynamo, the ICE and the EM can be activated simultaneously, as it is shown in the Figure 2.18. Then, the series topology is used for the process of conversion of mechanical to electrical energy, and the parallel configuration is used for the hybrid functionality.

Figure 2.18: Prototype for PrashannaRangan et al. (2017)

Morandin et al. (2014) designed, simulated and prototyped an Aprilia RS4 hybrid motorcycle, with a 125 c.c. ICE, an EM and the motorcycle's original transmission. The objective of carrying out the hybridization process was to improve the performance of the reference motorcycle in terms of torque, especially at low revs, by replacing the original electric alternator with a new EM and connecting it directly to the ICE.

The main requirements of this project were the low weight and volume of the energy storage system, which required high performance and energy autonomy, as well as a longer service life.

Experimental results confirmed that the final torque profile meets the design expectations. Acceleration time (0 to 60 km/h) decreases by 16% and top speed increases by 18%. Moreover, these performances were achieved by increasing the total vehicle weight by only 15%.

Figure 2.19 shows an adaptation of an internal stator in the ICE, the location of the batteries and control unit in the compartment under the driver's seat, and the parallel mounting of the electric machine with the combustion engine.

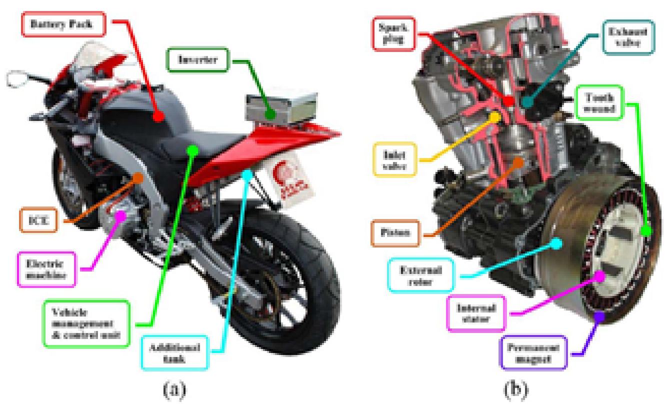


Figure 2.19: Prototype for Morandin et al. (2014)

Finally, Polanía-Restrepo et al. (2020) proposed a coupling system for the conversion of a Street type motorcycle with a 125 c.c. ICE by installing a 3 kW hub electric motor on the rear wheel powered by a lithium battery.

As for the coupling, a Hub-type EM cover was designed to allow direct connection to the sprocket which is driven by the chain connected to the ICE and allows the driving modes: electric, combustion and hybrid.

This approach allowed the motorcycle to be driven in electric mode for speeds below 20 km/h, especially for urban driving cycles, and to be driven by the ICE for higher speeds. Furthermore, in a driving cycle of 1140 s, the electric motor can work about 35% of the total cycle, reducing carbon monoxide (CO) and hydrocarbon (HC) emissions.

The starting point is an individual design, where the task has been clarified, defined and described with the help of the requirements. These represent at the same time the measure for the evaluation of the product. The aim is to define a solution concept that describes the physical and logical characteristics of the product. Furthermore, the functionalities, to which are assigned appropriate operating principles and/or solution elements and the fulfillment of the functions, are evaluated compared to the overall context of the system.

2.5 Results of the state of the art

It is found that all the articles aim to the conversion of an existing motorcycle reference, none of them assumes the challenge of an initial development, from which it can be said that having already geometric and mechanical limitations can increase to a greater extent the difficulty of performing this type of process. It is also observed that used ICEs are mostly not greater than 150 cc, from which it is concluded that there are only developments or prototypes for low displacement motorcycles.

Although in these articles it was possible to obtain certain characteristics of mechanical designs, couplings, topologies of operation, among others, all are different from each other, no prototype has similar or equal considerations, in the way of performing the conversion beyond the topology applied.

As an opportunity for future research, it is evident the need for a sequence to analyze each case of conversion, allowing not only the conversion of a reference of motorcycle but also a broader segment of motorcycles. That is, an orderly way to carry out a hybridization process in this means of transport, also the challenges in all works are referred to the coupling of both engines and the space available to make modifications without causing alterations in the characteristics of stability, maneuverability and standardization in the motorcycle.

Regarding the methodologies used in the motorization modification projects, only 2, which is equivalent to 13.3% of the articles found, mention or refer to a research methodology. Utama and Didi (2015) defined a 4-stage methodology, where a physical model is established, a finite element model where tests are performed for the selection of the material and the mechanical properties. The methodology used for Polanía-Restrepo et al. (2020) is based on a VDI methodology, which deals with the steps for the design of mechatronic systems, consisting of 3 stages where the first is the general cycle of problem solving at the micro level, then the V-shaped model at the macro level, and, finally, the predefined process modules to repeat the operation during the design of mechatronic systems.

Chapter 3

Methodological Proposal

3.1 Structure of the methodological proposal

Based on the research opportunity found after reviewing the state of the art, a methodology is proposed to establish the sequence of how to develop a modification project in the motorization of a two-wheeled vehicle and the relationship between its mechanical systems.

This is carried out through the analysis between variables of the different systems of a case study and with the integration of tools used in design and redesign methodologies, establishing the phases, stages and tools of a methodological proposal that allows standardization in a given family of products, this proposal can be seen in the Figure 3.1.

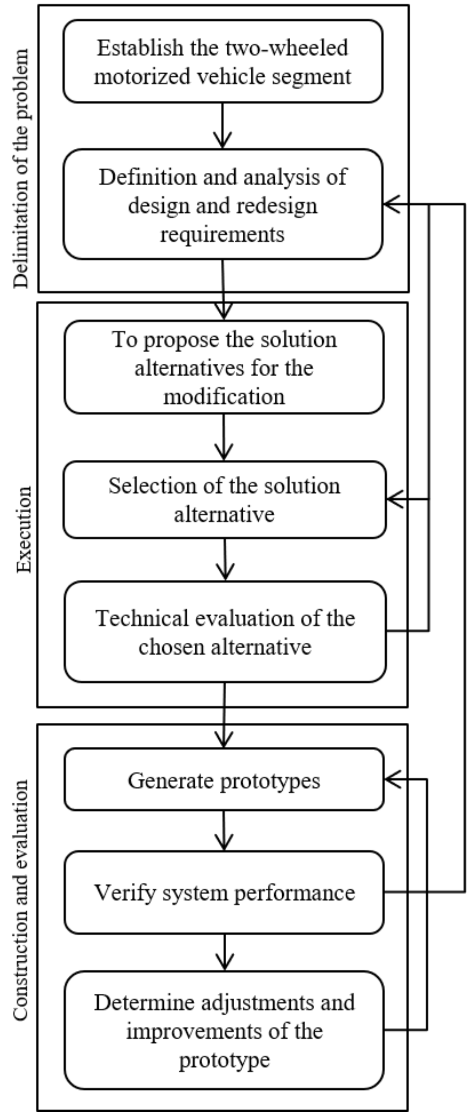


Figure 3.1: Methodological proposal by Authors

Next, the different stages of the methodology are explained.

3.1.1 Stage 1: Establish the two-wheeled motorized vehicle segment

At this stage, the aim is to define the segment on which the redesign research will be focused, i.e., the group on which the motorization modification will be carried out is selected.

Tools

When conducting a market study of a product, market competition data, manufacturers, costs and other characteristics pertaining to the product as such are known, in addition to obtaining information about the users and their needs or desires according to their profile.

1. Market research

Demographic information, such as gender, age, family and marital status, income, education, and occupation.

Geographic information, this information corresponds to specific cities, or it can even mean the country of residence of a client, i.e., it refers to the location of the interest group and the conditions or characteristics of this space.

Psychographics, such as social class, lifestyle, and personality traits.

2. User research

Demographic information, this is composed of user surveys, search trends or heat maps, in order to define specific customer traits and behaviors.

3.1.2 Stage 2: Definition and analysis of design and redesign requirements.

In this stage the user requirements are collected. These are related to a desire or a demand provided by the customer, user or the problem.

After this, the references selected in stage 1 of the two-wheeled motorized vehicles are broken down by parts by means of the contact matrix, where relationships between them are established and the criticality of modification that each one has is concluded. The information of the products belonging to the defined market is extracted by means of a characterization of the systems in order to establish work ranges, limitations, similarities or differences between them.

Finally, they are hierarchized with the help of the tool designed, so-called the relationship matrix

Contact matrix

This tool was designed in order to identify the relationships between mechanical systems by means of the contact existing between the parts that compose them, thus defining the critical parts according to the number of contacts and the systems that can be most affected by modifications.

Steps

1. The matrix comes pre-set with the parts and mechanical systems where it is possible to make modifications in the motorization of a two-wheeled vehicle according to the results obtained from the literature, as it is shown in the figure 3.2.

Two-wheeled motor vehicle systems	**Front braking system**				**Rear braking system**				**Front traction system**				**Rear Traction System**				
	Brake bell	Drum / Disc	Direct Drive	Indirect Drive	Brake bell	Drum / Disc	Direct Drive	Indirect Drive	Pneumatic	Rhine	Spokes / Blades	Supporting block	Pneumatic	Rhine	Spokes / Blades		Pneumatic
	Dragging system					**Front damping system**		**Rear damping system**		**Main support system**	**Front support system**		**Rear support system**			**Propulsion system**	
	Sprocket	Screws	Chain	Output sprocket	Tensioner	Shock absorber spring	Piston	Shock absorber spring	Piston	Chassis	Swing arm	Handlebar	Swing arm	Through shaft	Chassis support shaft	Combustion engine	Gearbox

Figure 3.2: Contact matrix step 1

2. The first horizontal piece is related to all the vertical pieces and a number 1 or an indicative

is placed to identify that there is a point of contact between them. The contact matrix can be seen in the Appendix A.

3. The quantity of 1's is added and hierarchized from highest to lowest, where the parts with the highest number of relationship indicates that they are critical parts for the system, since making a modification in these means a greater influence on the vehicle. In addition, system by system are compared and the relationships that exist between them are verified outside the intersection.

Characterization table

It allows to obtain the dimensional, physical and mechanical characteristics of the parts that were found to be critical in the contact matrix. A characterization table is made for each critical part found.

Steps

1. To fill in the tables, the reference rows are filled in with the vehicles selected in the market study, which are only those defined for the motorization classification.

2. In the columns under characteristics, the characteristics to be compared between the references are placed, such as width, weight, volume, among others.

3. Finally, the table is filled with the data found and compared. This in order to find similarities and differences between the vehicles. It is clarified that each characterization table is made on the pieces that were critical in the previous matrix.

By having the results of the characterization tables, which are values or ranges, these serve as the base information to fill the limit box in several of the specifications, in an objective way, in the relationship matrix, since they are known and denoted data. A schematic of a characterization table is shown in the Figure 3.3.

	Characteristic 1	**Characteristic 2**	**Characteristic 3**	**Characteristic n**
Reference 1	Value 1	Value 2	Value 3	Value n
Reference 2	Value 1	Value 2	Value 3	Value n
Reference 3	Value 1	Value 2	Value 3	Value n
Reference n	Value 1	Value 2	Value 3	Value n

Figure 3.3: Characterization tables template

Relationship matrix

The requirements and their boundaries are entered into the designed relationship matrix, resulting in a hierarchy of requirements and specifications, in order to obtain a checklist of requirements that can establish a design order.

Steps

1. Fill in the user requirements, specifications and limit fields, see the Figure 3.4.

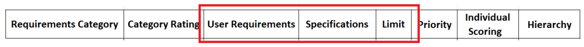


Figure 3.4: Relationship matrix step 1

2. In the category rating box, select the priority that the category represents over the others, on a scale of 1 to 5, where 5 is the highest priority and 1 is the lowest. This priority is chosen by the researcher and answers the question "In what order of importance does each category have for the development of the project?, see the Figure 3.5

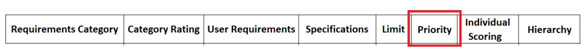


Figure 3.5: Relationship matrix step 2

3. The priority that the specification represents over the others within the same category to which it belongs is selected on a scale of 1 to 10, see the Figure 3.6

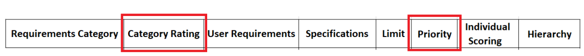


Figure 3.6: Relationship matrix step 3

4. With the category rating and the priority, the individual score of the specifications and the hierarchy is automatically filled in, in which the most important specifications are given a position and a check list of specifications is updated in order to have an evaluation and testing process later in the stage 7, see the Table 3.1.

Requirements Category	Category Rating	User Requirements	Specifications	Limit	Priority	Individual Scoring	Hierarchy
Cost Objective							
Performance							
Service Life							
Manufacturing							
Environment							
Maintenance							
Dimensions and weights							
Comfort and safety							

	Check list of specifications
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	

Table 3.1: Relationship matrix template

3.1.3 Stage 3: Propose the solution alternatives for the modification.

In this stage the motorized two-wheeled vehicle is related to the requirements for the modification of the motorization by means of a functional structure that allows to propose different alternatives for the objective. The objective is to give solution to the needs that are presented with the engineering specifications. Initially, a black box and a transparent box is used to find the main characteristics of operation. Then, according to the main functions, the element or elements that cover each function and different alternatives are proposed in a morphological matrix as this is recommended for new products, services or modifications to existing products.

NOTE: There are other tools for generating solutions that can be used, it is the researcher's choice, but the morphological matrix is recommended for the above reasons.

3.1.4 Stage 4: Selection of solution alternatives.

The purpose of this stage is to qualify the possible solutions proposed in the previous phase, i.e., the solution routes obtained in the morphological matrix are used and evaluated, which allows selecting the most appropriate one according to the evaluation criteria and defining the best solution.

Evaluation matrix: The evaluation matrix is predefined in the concepts, so that these are the same as the categories of the relationship matrix, in order to verify the fulfillment of the user's requirements. The valuation percentages are assigned in the same way as the importance given to the categories in the relationship matrix, i.e. if the cost category in the relationship matrix has an importance of value 5, in the evaluation matrix this will have a higher percentage than the others, the evaluation matrix template is shown in the Figure 3.7.

EVALUATION MATRIX											
CONCEPTS				1	2	3	4	5	6	7	8
CONCEPT NAME			PERCENTAGE OF VALUATION	Route A	Route B	Route C	Route D	Route E	Route F	Route G	Route N
CRITERIA	1	Target cost									
	2	Performance									
	3	Useful life									
	4	Manufacturing									
	5	Environmental									
	6	Maintenance									
	7	Dimensions and weights									
	8	Comfort and safety									
		TOTAL		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Figure 3.7: Evaluation matrix template

3.1.5 Stage 5: Evaluation of the chosen alternative.

Since the methodology is focused on a mechanical product, the chosen solution must comply with analytical verification in order to know if it is a viable functional solution, such as:

- Static analysis, see the Figure 3.8

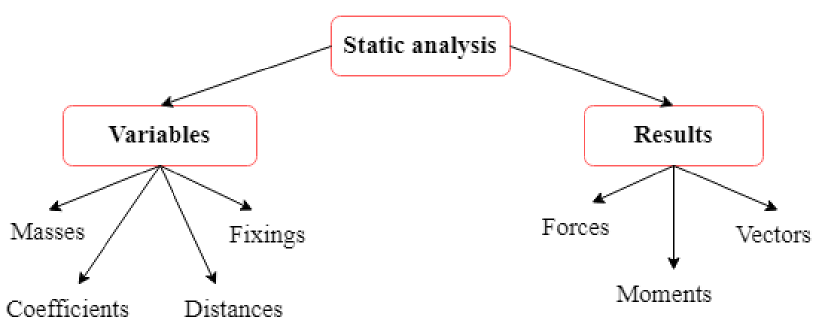


Figure 3.8: Static Analysis

- Stress analysis, see the Figure 3.9

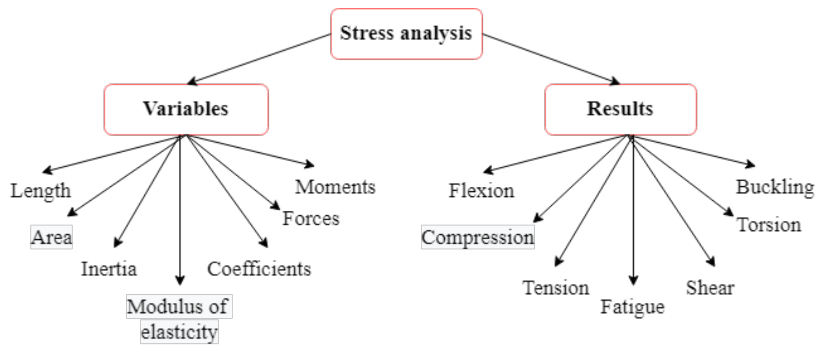


Figure 3.9: Stress Analysis

- Material analysis, see the Figure 3.10

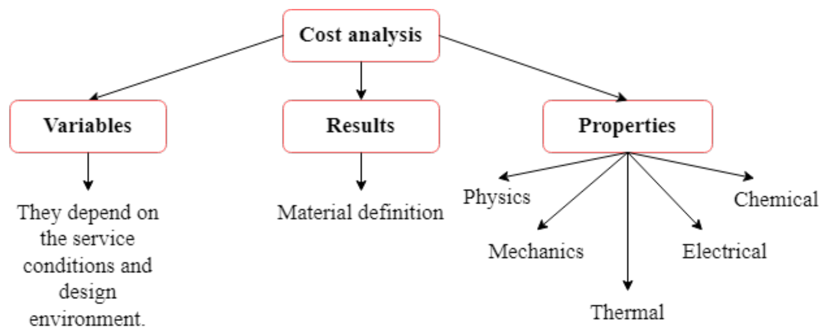


Figure 3.10: Material Analysis

- Manufacturing analysis, see the Figure 3.11

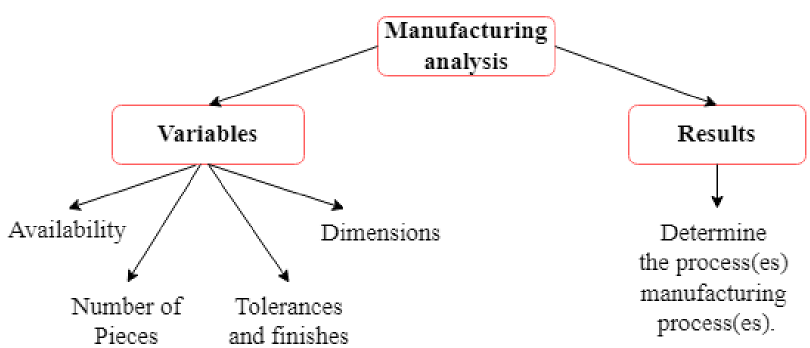


Figure 3.11: Manufacturing Analysis

- Cost analysis, see the Figure 3.12

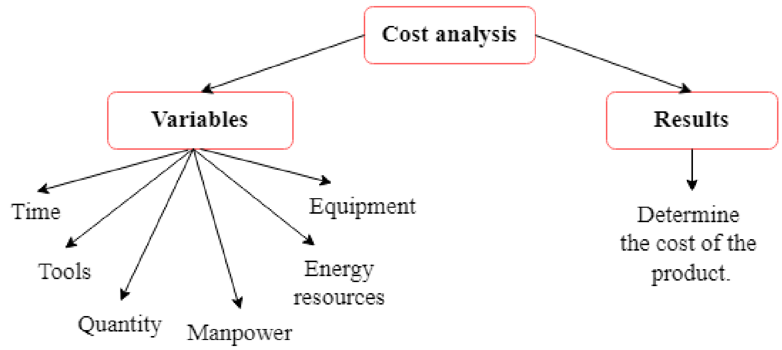


Figure 3.12: Cost Analysis

The basic technical analysis, variables, results and some properties are presented as aids to the researcher.

3.1.6 Stage 6: Prototype generation.

The purpose of a prototype is to validate the initial hypothesis, testing it to detect flaws or opportunities for improvement. For this purpose there are different methods such as papyroexia, handcrafting, injection, 3D printing, among others.

In this case the recommended methods to implement are those that have as a result a solid figure that supports to scale the values of the physical and mechanical properties obtained in stage 1 and stage 2. These prototyping techniques are: 3D prototyping, machining, injection models.

3.1.7 Stage 7: Verify the operation of the system.

Functional tests are performed for the prototype or prototypes produced. Since the purpose of this methodology is the standardization of the modification, at this stage the main objective of the application of the methodology is evaluated.

For this purpose, the system performance tests depend directly on the check list of specifications generated in the previous stages.

The items that are not necessarily independent can be related and they can be evaluated simultaneously in the same test.

For example, in the Table 3.2, for the Item 1, "increase in total mass", in the ratio matrix there is a limit value, and the associated test is to weigh the components and verify that this value was not exceeded. For the Item 2, "IP degree of protection", in the Relationship Matrix the limit is x=IP 55, the test objective is to verify with water, dust and other tests that the designed system achieves this objective, and so on for the other items.

	Check list of specifications
1	Increase in total mass.
2	IP protection degree.
3	Increase in total mass.
4	Maximum width allowed.
5	Equivalent energy efficiency.
6	Maximum torque
7	Maximum power
8	Volume occupied on the motorcycle.

Table 3.2: Example development stage 7

3.1.8 Stage 8: Determine prototype adjustments and improvements.

From the results of the stage 7, the changes or corrections to the prototype are determined and the prototype is returned to stage 6 to generate the prototype again, this process is repeated until the objective is met.

This methodology is composed of general phases and stages, but the proposed tools are specifically focused and pre-established for motorized two-wheeled vehicles.

Chapter 4

Case Study

The design of a standard hybridization kit for motorcycles in a certain segment of the market is used as case study for the validation and implementation of the proposed methodology. This modification in the motorization is proposed in the rear drive train because it is the continuation of a previous project where the front modification had been discarded and HUB type engines had been defined for this project.

4.1 Stage 1. Analysis of the motorized two-wheeler market in Colombia.

The first step in the process of developing an engine modification for motorcycle conversion is to analyze the current vehicle fleet in Colombia to determine its impact on the market. The information analyzed on the motorcycle market has been provided by Fenalco (2019), which is a Colombian entity that seeks the development of trade, and de Vehiculos Automotores (2019), which is the Colombian association for sustainable mobility. The purpose of this information is to select the market segment and motorcycle references to intervene for the modification of the motorization.

Figure 4.1 presents the motorcycle market, accumulated in 2019, classified according to engine displacement, and it can be concluded that almost 68% of the registered motorcycles have displacements below 135 c.c. Likewise, it can be observed that the other ranges contribute less than 13% each. Therefore, it is evident that a modification should be made to two-wheeled vehicles in the 0-135 c.c. range, since this is the one that affects the most significant part of the motorcycle fleet.

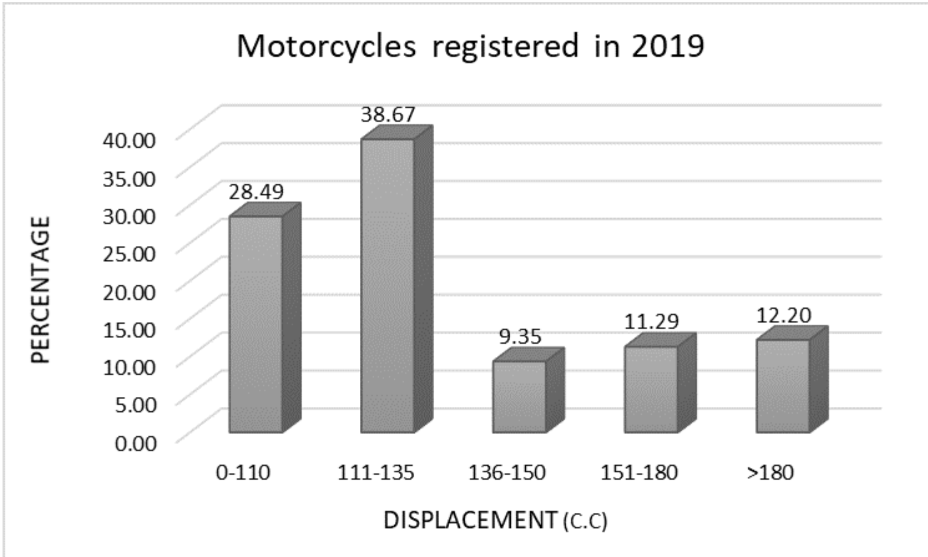


Figure 4.1: Motorcycles market distribution according to engine displacement

Figure 4.2 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.

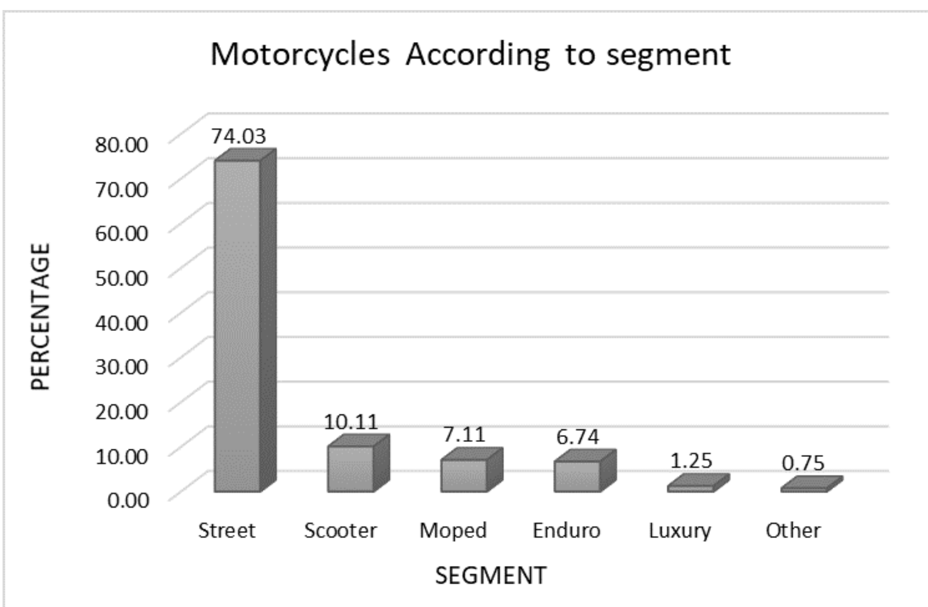


Figure 4.2: Motorcycles market distribution by segment

Considering the information supplied by Fenalco (2018) 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 4.3 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 making the engine modification in this family of references, in order to achieve standardization and cover the largest percentage of the market with street motorcycles.

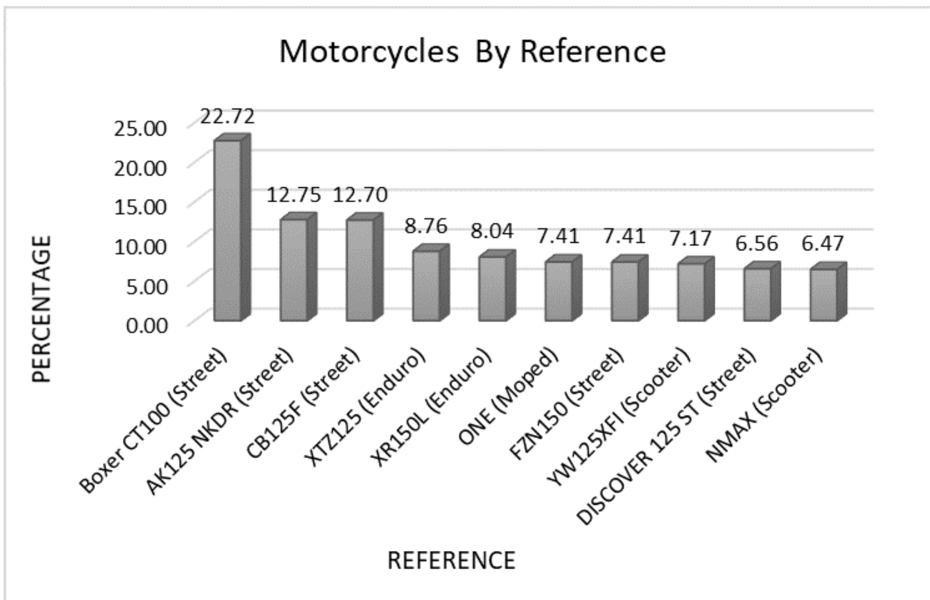


Figure 4.3: Best selling motorcycles in Colombia.

From the above it is concluded that in order to have a greater impact on the Colombian market when designing a modification in the motorization of a family of motorcycles, the street segment from 0 to 135 cc is defined and the references to carry out the studies are: Boxer ct100, Discover 125, Honda cb125f, and AKT NKD125.

4.2 Stage 2. Definition and analysis of design and redesign requirements.

4.2.1 Contact Matrix

The developed contact matrix can be seen in the Appendix A, in the Figure A.2, and it was obtained that the critical parts of the motorcycle were the brake bell, the through axle, the swing arm and the chassis. These parts obtained a greater number of contacts, that is to say, that they have a greater number of relations with other mechanical parts. The system with more relations is the rear support system, followed by the main support system, and, finally, the rear traction system. This is useful because it is possible to show in advance which system could suffer some change due to the intervention of another system.

Rear support system is related to: Rear Brake System, Rear Drive System, Drag System, Rear Damping System and Main Support System, with this it would have contact with 45% of the motorcycle systems, which makes it the most important mechanical system for any modification, due to the fact that it can affect that percentage of the vehicle.

After this, the parts and systems previously found are characterized in order to find similarities and differences.

4.2.2 Characterization tables

In this section different characterizations, geometric, mechanical and dimensional, are made to establish the similarities and differences of the critical parts between the four selected street motorcycles, so that the modification in the motorization is applicable to all the references, without significantly affecting the mechanical systems.

With respect to the through axle all had the same shape the only thing that varied was the diameter with differences within 1 mm and the length of the discover and the cb125f were 2 cm longer than the boxer and the nkd125. Of the latter the through axles were identical. Finally, with the brake system, all are drum type brake, with the same way of operation by cam and pedal, in the section 4.2.3 their characteristics are evidenced.

Regarding the chassis, this is similar in all motorcycles and is directly related to the selected market segment, it is a round tube chassis that goes from the steering to the grill as a single body, where the ICE is mainly supported and joins the rear support system and front support system.

The swing arm is one of the most important parts to be considered for the feasibility of the conversion since it has direct contact with the chassis, the electric hub motor, and the suspension system. So, the Figure 4.4 shows the main dimensions to be considered and the Table 4.1 presents the numeric values.

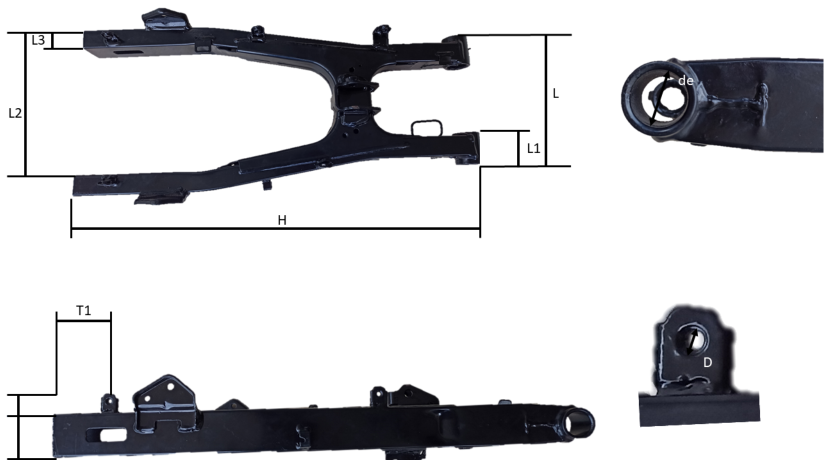
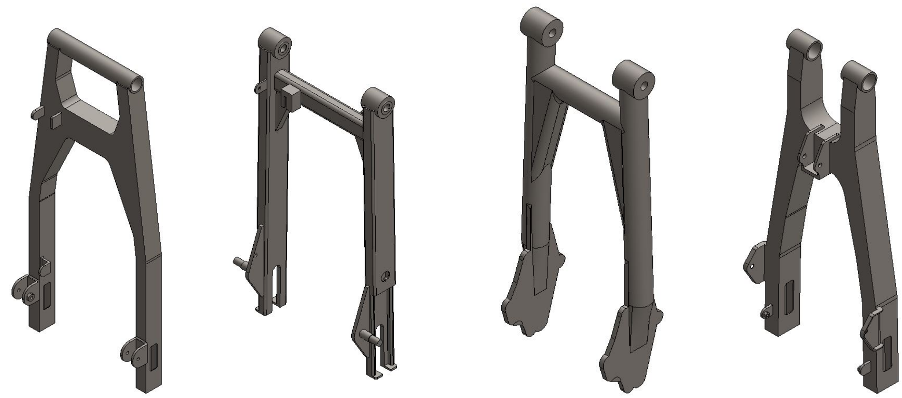


Figure 4.4: Indications for the swing arm

Table 4.1: Swing arm measurements

Characteristic	Bajaj Boxer CT100	AKT NKD 125	Bajaj Discover 125ST	Honda CBF125	Units
de	10,1	12,2	27,8	24	mm
L	195	232,9	201,5	188,5	mm
L1	35	14,8	47,8	21	mm
L2	177	244,1	199,6	270	mm
L3	17,6	20,6	30,7	20,5	mm
H	480	463	620	593	mm
T1	76,6	78,8	50	81,1	mm
T2	38,4	16,5	14,7	23,9	mm
A	26,4	36,4	50,6	40,2	mm
D	11,8	14	4,6	10,87	mm

The Figure 4.5 presents the different CAD models for each reference of the motorcycles.



(a) (b) (c) (d)

Figure 4.5: CAD model of selected motorcycles swing arms: 4.5(a) Honda CBF125, 4.5(b).AKT NKD 125, 4.5(c) Bajaj Boxer CT100 4.5(d) Bajaj Discover 125ST,

The longest swing arm (H measure) is that of the Bajaj Discover 125 and the smallest is that of the AKT NKD 125. Although the difference between the latter and the Bajaj Boxer CT100 is less than 2 cm, the motorcycle with the largest working space, i.e., the widest is the Honda CB125f and the smallest is the Bajaj Boxer CT100. It is concluded that the maximum working space for the coupling system to the engine is that of the Boxer 177.05 mm.

Additionally, it was decided to perform a general characterization of the four motorcycles, in order to obtain the similarities and differences, not in detail as previously evidenced, but in a macro way.

4.2.3 Mechanical characterization

Table 4.2 summarizes the values for different common mechanical variables for all the four selected street motorcycles.

Table 4.2: 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

It is observed in the table 4.2 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.

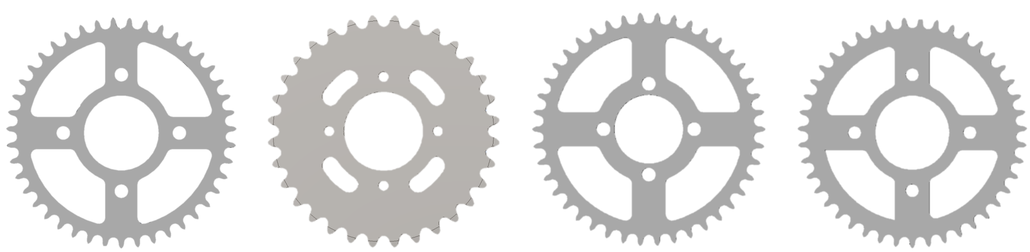
In addition, the front suspension is the same for all motorcycle references, as well as the braking system for all. The rear suspension and compression ratio differ only in the Discover reference. The load capacity works in the range of 130 to 170 kg. These data are important when adding components to the bikes because they are related to fuel consumption and the effects they can have on damping.

But, in general, the bikes are very similar.

The sprocket is a very important mechanical part since it allows the mechanical power transmission from the gearbox to the rear wheel and it is important to keep this part in the conversion process. So, this component is characterized with the features presented in the Table 4.3 and the different sprockets were modelled as it is shown in the Figure 4.6.

Table 4.3: Sprocket measurements

Characteristic	Bajaj Boxer CT100	AKT NKD 125	Bajaj Discover 125ST	Honda CBF125	Units
Number of teeth	42	38	43	43	ul
Outer Diameter	175	169,3	178,3	178	mm
Inner Diameter	51,8	58	57,7	58	mm
Roller Diameter (Chain)	8,5	8,5	8,5	8,5	mm
Screw Hole Diameter	10,6	7,5	10,2	10,8	mm
Number of Screw Holes	4	4	4	4	ul
Distance between center of the sprocket-center of the Screw Holes.	34	39,7	44,7	44,8	mm
Thickness	7	6,6	8,5	7,4	mm



(a) (b) (c) (d)

Figure 4.6: CAD models of the sprocket of selected motorcycles: 4.6(a) Honda CBF125, 4.6(b) AKT NKD125, 4.6(c) Bajaj Boxer CT100, 4.6(d) Bajaj Discover 125ST

The largest sprocket is that of the Discover 125ST and the smallest is that of the AKT NKD 125. Between these sprockets there is a difference of teeth equal to 5, all sprocket references have the same number of bolt holes, the sprocket of the discover and the cb125f are equal in all their characteristics. The Discover sprocket is the thickest being 1.05 mm larger than that of the Honda CBF125, 1.5 mm larger than that of the Boxer CT100 and 1.9 mm larger than that of the AKT NKD 125.

4.2.4 Relationship Matrix

To make the relationship matrix, first the PDS of the product must be obtained since the matrix uses the user requirements, the engineering specifications and their limits. It is decided to make the PDS after the contact matrix and the characterization tables so that these previous steps facilitate the definition of the working ranges or limits of the engineering specifications.

4.2.4.1 Product design specification (PDS)

For the development of the PDS, the methodology proposed by Pugh Pugh and Clausing (1996) was used to identify a list of applicable requirements for modification in motorization. These were grouped by categories such as cost, performance, maintenance and environment, to which specifications were added to define the design parameters.

Each requirement and specification listed in the Table 4.4 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.

Table 4.4: Product Design Specifications for the kit of hybridization

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

There are design challenges such as: the modification must not exceed a cost limit, and it must not affect maintenance times or the service life of the motorcycle components. In addition, the motorcycle must have the same or better mechanical and energy performance than the original motorcycle, it must not affect the safety, ergonomics or aesthetics of the motorcycle and, finally, it must seek simplicity in manufacturing and assembly.

4.2.4.2 Relationship matrix completed

The complete relationship matrix could be observed in the Appendix A, is composed of 27 user requirements, translated into 31 engineering specifications with their respective limits. Of the 8 categories, 3 have been qualified as the most important, which are cost, performance and dimensions, that is to say, with prioritization of 5, later when giving the prioritization to the engineering specifications it is obtained that 16 of them are prioritized with values between 8-10, the weighting is made with both qualifications and the check list of specifications is obtained automatically and its hierarchy with the purpose of prioritizing and organizing an evaluative list at the moment of the design, redesign and standardization.

Repeated specifications are highlighted because although they are found in this way, they do not belong to the same category and therefore have a different evaluation, which corresponds to different places in the list, it should be remembered that the check list is made in order to facilitate the evaluation during the development stages.

4.3 Stage 3. Propose the solution alternatives for the modification.

4.3.1 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 initiated with a black and a transparent box presented in the Figure 4.7, in order to identify the functions performed by the kit, with their related flows of energy (segmented line), matter (continuous line) and information (dotted line).

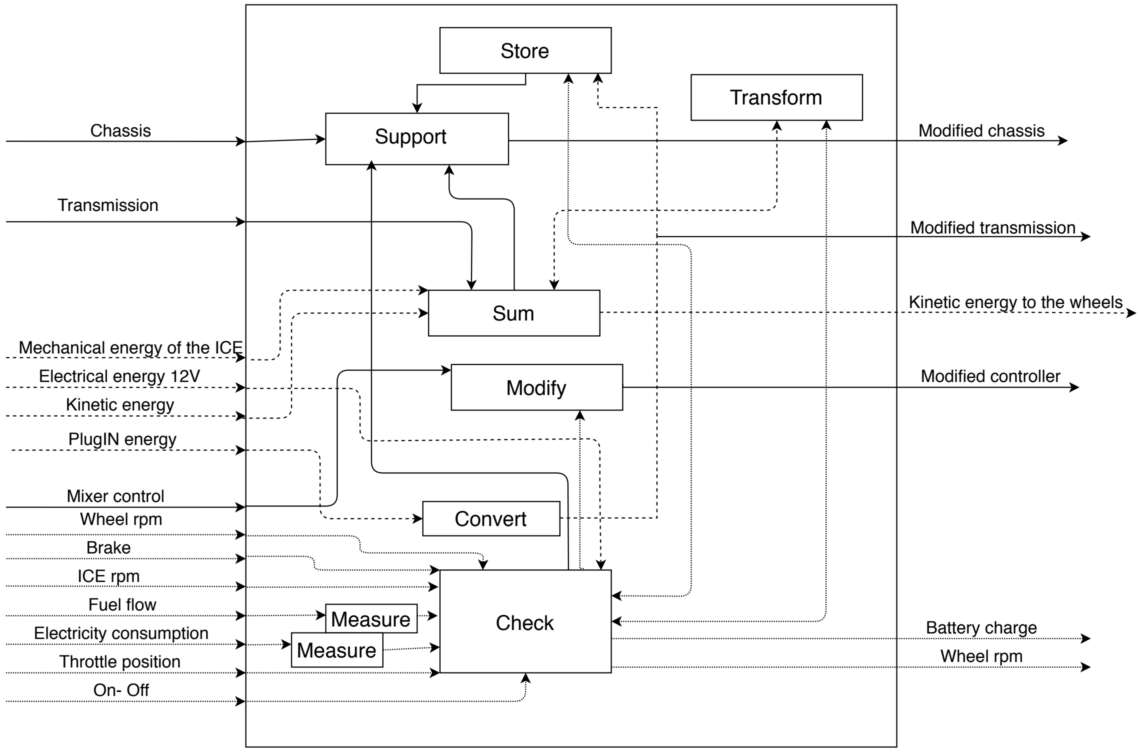


Figure 4.7: Transparent kit box

There are 9 main functions, but the functions that are directly related to the change of motorization and its mechanical requirements are adding, supporting, storing and transforming, mainly related to material flows that are the chassis, the transmission, the energies associated with the engines, and for information the connection signal between them.

With these functions, the morphological matrix is constructed in order to propose possible solutions to the functions previously found.

4.3.2 Morphological matrix

Remembering that the functionality of the hybridization kit is a modification in the motorization of the rear drive train together with an already defined component such as a HUB type electric motor, the following morphological matrix is proposed that seeks to generate and propose solutions for each function found in the previous section and also that this solution can be related to the previously defined components. The matrix is presented in the Figure 4.8.

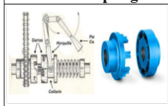
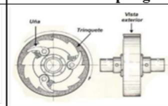
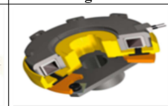
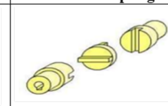
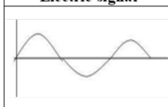
Add	**Claw coupling**	**Ratchet coupling**	**Electromagnetic clutch**	**Oldham coupling**	**Planetary gear**
					
Support	**Bell**	**Pinion**	**Sprocket**		
					
Transform	**Electric signal**	**Mechanical Signal**	**None**		
		Mechanical Signal			
Store	**Batteries**				
					

Figure 4.8: Morphological matrix

For a better understanding of the morphological matrix and its options, each option for the "add" function, related with the interaction between the energies coming from each motor, will be defined below.

- **Claw coupling:** it consists of two adjacent plates, which have in their contact area a tooth with inclined and straight surfaces, so that the movement is transmitted only in the direction that the parts of the straight tooth come into contact, since in the opposite direction the oblique tooth prevents the dragging of one of them to the other. The contact between the two plates is always ensured by the action of a spring, and the system can also have a lever that allows uncoupling at will. Gutiérrez (2010)
- **Ratchet Coupling:** It consists of a control shaft with a "Ratchet", on which the controlled shaft has two or more "Claws" that by means of springs are in contact with the ratchet teeth. As in the previous coupling, the movement is only transmitted in one direction, since in the opposite direction the claws with their rounded backs slide over the teeth. Gutiérrez (2010)
- **Electromagnetic coupling:** The electromagnetic clutch is a component that works on the principle of the electromagnet. This means that an assembly formed by a coil and an iron core generates a magnetic field when the iron is excited by an electric pulse. Motor OK (7 03)
- **Oldham Coupling:** It is a three-piece assembly consisting of two anodized aluminum hubs mounted on a plastic center disk. The teeth of the hubs enter the disc grooves with low pressure and ensure zero backlash torque transmission. During coupling operation the hubs slide in a direction perpendicular to each other in the disc grooves to compensate for misalignment without affecting torque transmission. Ruland Manufacturing Co., Inc. (2020)

- **Planetary gear coupling:** it is a set of gears with the input shaft and the output shaft aligned. A planetary gearbox is used to transfer the highest torque in the most compact form (known as torque density). Ingeniería y mecánica automotriz (2020)

The eight routes defined for possible architectures are defined in the following:

- Route A: Claw coupling - Bell - Mechanical signal - Batteries.
- Route B: Ratchet coupling - Bell - Mechanical signal - Batteries.
- Route C: Ratchet coupling - Bell - Electrical signal - Batteries.
- Route D: Electromagnetic clutch - Bell - Electrical signal - Batteries.
- Route E: Electromagnetic clutch - Sprocket-Electrical signal - Batteries.
- Route F: Electromagnetic clutch - Output pinion - Electrical signal - Batteries.
- Route G: Oldham coupling - Sprocket - None - Batteries.
- Route H: Planetary gear - Sprocket - None - Batteries.

4.4 Stage 4. Evaluation matrix

In the evaluation matrix shown in table 4.5, the evaluation process of the solution alternatives defined in the morphological matrix is carried out.

EVALUATION MATRIX											
CONCEPTS				1	2	3	4	5	6	7	8
CONCEPT NAME			PERCENTAGE OF VALUATION	Route A	Route B	Route C	Route D	Route E	Route F	Route G	Route N
CRITERIA	1	Cost objetive	15%	2	5	5	3	3	3	5	1
	2	Performance	15%	3	5	5	5	5	5	3	3
	3	Useful life	10,75%	1	5	4	3	3	3	2	2
	4	Manufacturing	12%	2	4	3	3	4	2	3	1
	5	Environmental	10,75%	4	4	3	2	2	2	4	4
	6	Maintenance	10,75%	4	5	4	3	3	3	4	4
	7	Dimensions and weights	15%	1	4	3	2	2	2	3	1
	8	Comfort and safety	10,75%	2	4	3	4	4	4	3	2
TOTAL				2,3	4,5	3,8	3,2	3,3	3,0	3,4	2,2

Table 4.5: Evaluation matrix

It can be concluded that the routes with the ratchet type couplings are the best qualified, followed by those containing the electromagnetic clutch. In spite of this, the selected route is route B, this obtained a better comparative evaluation in all the criteria.

The selected route passes to a stage of design and evaluation in more technical detail. If it is not possible or the route does not meet the technical requirements, the next route with better qualification should be evaluated.

Additionally, the comparison Table 4.6 between the selected route and the others is developed, in order to reaffirm the decision and observe the advantages and disadvantages to take into account.

Table 4.6: Solution Comparison

COMPARISON OF SOLUTION ALTERNATIVES	
ADVANTAGES	**DISADVANTAGES**
It is a system especially mechanical, this facilitates your maintenance.	By having an electrical signal incorporated, the process of communication with the controller would be resolved.
The mechanism of Ratchet has the possibility of more dimensions small.	The clutch allows a connection of the systems at higher speeds than the ratchet.
The quote or price of the ratchet coupling is 25 times less than that of the clutch.	
The ratchet coupling is located for immediate delivery, while the clutch can a need for a export.	
The life of mechanism is approximately 21 years, while the of the clutch is shorter.	

According to the selected route, the designs of the systems that relate the functions and the selected parts are carried out. Technical drawings are presented in the Appendix B.

4.5 Stage 5. Evaluation of the alternative.

In order to know the loads to which the system will be subjected, a static analysis of the parts of the rear drive train, swing arm, axle, pinion, and brake is carried out in which the torque and power of the combustion engine and electric motor can be combined to find the maximum torque transmitted by the motors and that the coupling system must withstand.

4.5.1 Analytical model of the engines

Since the coupling system is located in the rear drive train, it must withstand a maximum torque, which is obtained after the gearbox. In order to know the value to be supported, a dynamic model was implemented.

A mathematical model was applied to the kinematic chain of the four motorcycles selected and mentioned above. Using the data of the motorcycles delivered by the manufacturers, it was possible to recreate the operation of the engines to find the torque and power values that the coupling system must support.

With this, the torque and power curve of each motorcycle was obtained, in a range of revolutions between 2000 and 8000 RPM, finding the maximum speeds, torque and efficiency points of each one, in the same way for the electric motor, and later the sum of both curves was made and the operation points were found, that is to say, when the electric motor contributes, and when it is not efficient.

To find the speed of the motorcycle, first calculate the total ratio of each gear with the equation 4.1.

$$R_t = (A * C * D) \tag{4.1}$$

Where wheel speed, i.e. the engine speed multiplied by the total gear ratio 4.2.

$$R_n = RPM * R_t \tag{4.2}$$

then the equation that determines the speed of the vehicle as a function of the engine revolutions is 4.3:

$$Speed = \pi * (2 * B) * (R_n) * \frac{60}{1000} \tag{4.3}$$

A= Primary Relationship

C= Secondary Relationship

B= Gear ratio

D = Gear reduction

The expression is used to find the torque to the motorcycle wheel:

$$Torque_{Wheel}(N.m.) = Torque_{Motor} * A * B * C \tag{4.4}$$

To find the instantaneous power of the motorcycle we use the expression:

$$Power_{Instantaneous} = Torque_{Wheel} * RPM \tag{4.5}$$

The model was applied in the four motorcycle references. The results obtained in the torque specification are presented in the Figure 4.9 and the Figure 4.10.

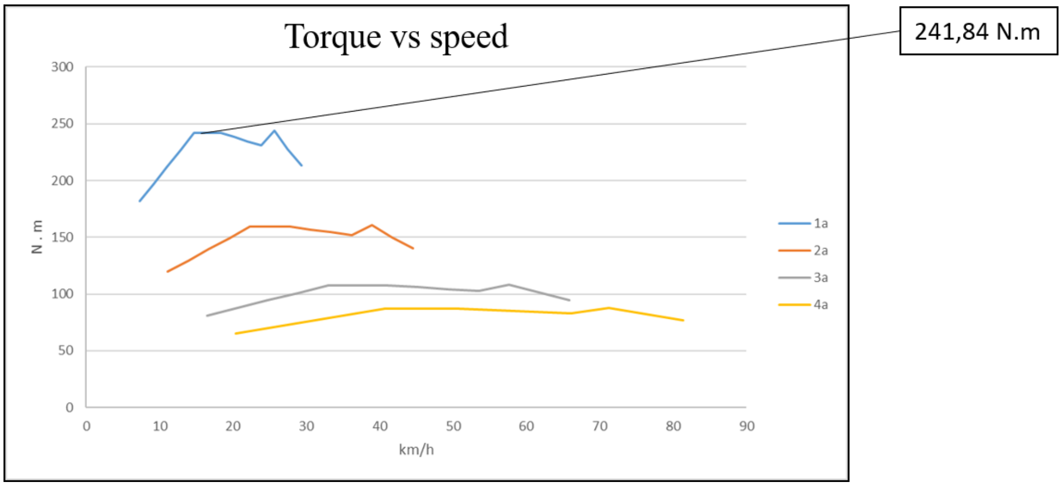


Figure 4.9: Results of the model applied in the boxer (Torque).

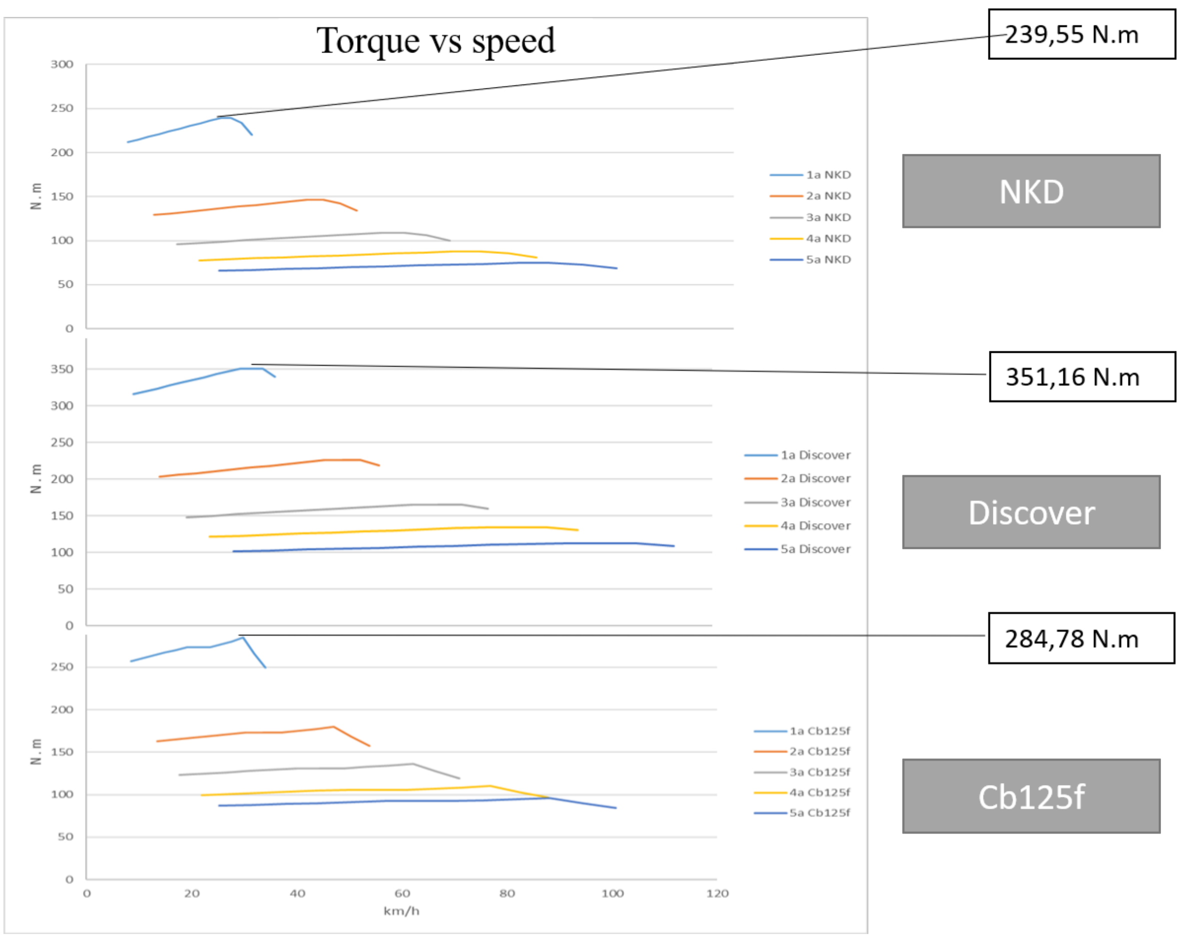


Figure 4.10: Results of the model applied in other references (Torque).

With these calculations, it is estimated that the torque that the coupling must support is 351.16

N.m and it is also observed that the maximum speed that the rear wheel can reach is around 120 Km/h. Then, the coupling must be capable of turning at 1100 RPM.

To find the operative curve of the electric motors, the data provided by the manufacturer was used, which are Peak power and maximum RPMs without load (No-load speed (NLS)).

With this data we want to obtain a function for the motor torque of the form,

$$Y = m * x + b \tag{4.6}$$

and for the power equation the expression

$$y = a * x^2 + b * x + c \tag{4.7}$$

.

Replacing the different values of the selected electric motors, the torque and power of the electric motor is presented in the Figure 4.11.

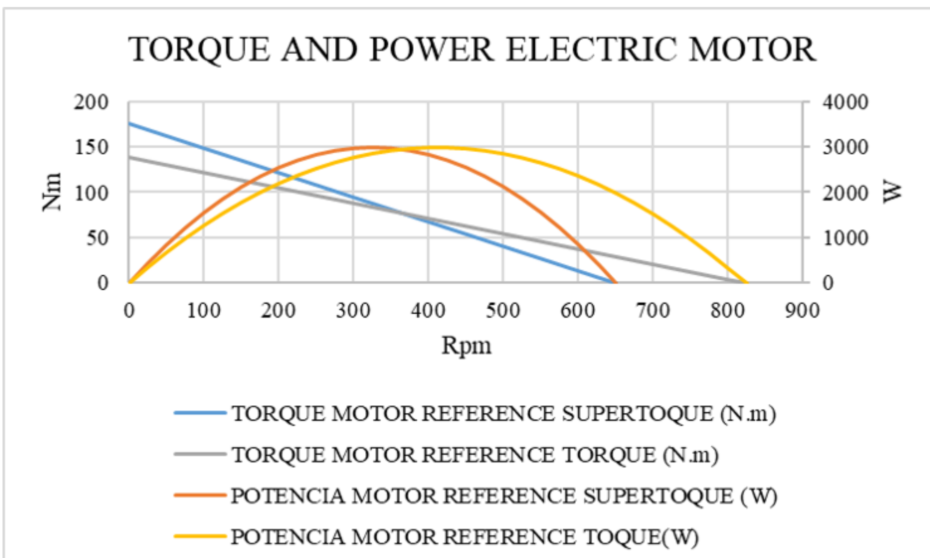


Figure 4.11: Electric motor model

The performance curve of the motors adapts to the characteristics of the motorcycles and to the requirements of use. Theser motors are the references **Super Torque** and **Torque.**

The efficiency point of the electric motors is around 325 rpm and 400 rpm, and at this point the Super Torque reference motor provides 176 Nm, and the Torque reference 139 Nm, i.e., they are efficient approximately between 70-90 km/h, the EM is more useful for starting motorcycles than for high speeds.

The "Super Torque" reference MS provides significant torque from 0 to approximately 625 RPM (70 km/h) while the "Torque" reference provides significant torque from 0 to approximately 823 RPM (90 km/h).

4.5.2 Static analysis of the rear drive system

The detailed analysis is carried out from the general to the particular, so the free body diagram presented in the Figure 4.12 depicts the forces acting on the rear power train. In the shaft analysis, the free body diagram is presented in the Figure 4.13, the loads corresponding to the supports of the elements, such as the bearings, the ends of the swing arm and the loads transmitted by the weights and supports of the systems in contact or related to it, that is, the transmitted loads, were located in the shaft analysis.

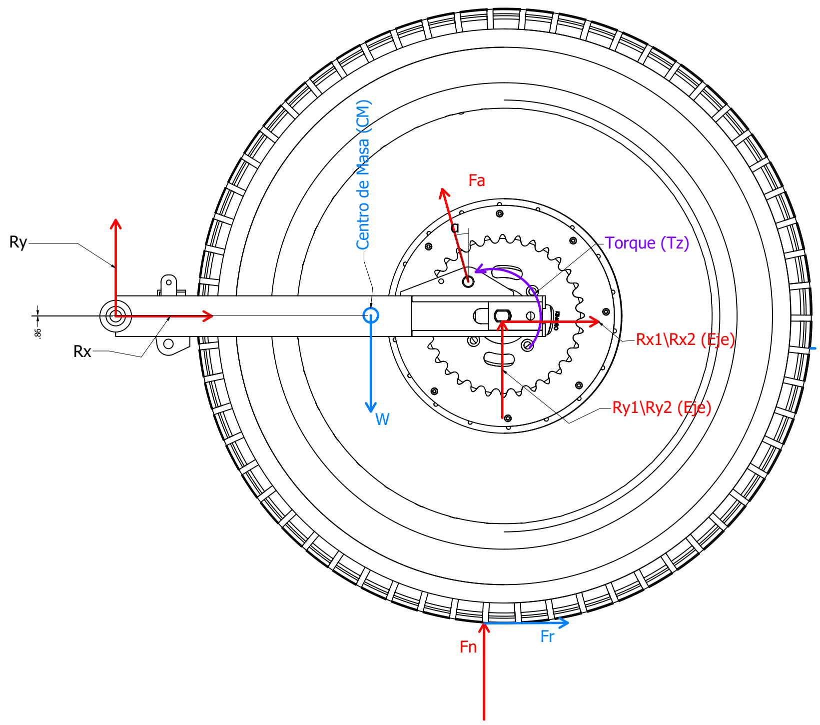


Figure 4.12: Free body diagram of the rear system.

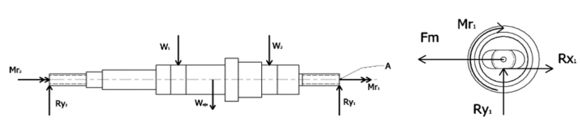


Figure 4.13: Free body diagram for the wheel shaft

The Table 4.7 describes the different forces considered in this analysis.

Table 4.7: Description of static analysis variables

Variable	Description
F_{m1} y F_{m2}	Feed force applied on the shaft transmitted through the bearing located in that position. Due to the symmetry of the shaft with respect to the point where the motor, rim and tire are supported, we assume a value of Fm/2
w_1 y w_2	Weight of the components supported on the shaft transmitted by the bearing located in that position.
w_{eje}	Axle weight. There is no value indicated by the manufacturer as a single component, therefore a weight of 1KgF is assumed.
R_{y2} y R_{y1}	Reactions applied on the shaft due to contact with the swing arm s in the weight direction.
R_{x2} y R_{x1}	Reactions applied on the shaft due to contact with the swing arm and turnbuckle in the direction of the feed force (F_m)
M_{r1} y M_{r2}	Reactions applied on the shaft due to the flat geometry it has on the faces where the shaft rests on the swing arm s. It is not possible to obtain its values analytically without making another assumption in the system.
M_{RT}	Value product of the sum of M_{r1} y M_{r2}.

Continuing the analysis, the known data of the parts are extracted, such as the weight, friction coefficient, dimensions, among others that can be observed in the tables 4.8, and 4.9.

The values shown in the table 4.8, regarding motorcycle parts such as: rim, tire, among others, were obtained from the assembly in CAD software performed previously, where the mass of these elements was measured for the AKT NKD 125 motorcycle. For the commercial parts, such as bearings, and motor, their characteristics were obtained from the data sheet supplied by the dealer. The other parts correspond to self-designed parts and their weight was estimated using the density of the material with which the prototype of the final part is going to be made.

Table 4.8: Known component weights.

Component name	Weight (g)
Coupling	313.07
Bearing CSK40PP	500
Motor Cover	550.183
16006 Bearing	136
Motor + Shaft	13000
Rear Sprocket	805.949
Sprocket Screws	75.8
Engine Cover Screws	15.872
Rhinestone	2350.363
Tire	162.864
Spokes-Rhine Screws	162.864
Spokes-Rhine	151.704

Table 4.9: Normal force and others.

Parameter	Value
Normal	1960 N
Coefficient of friction	0.56033
Friction Force	1098.247 N
Pneumatic spoke	0.3196 m

The normal force values were measured by resting the rear wheel of the motorcycle on a 200 kg capacity scale, in order to obtain the weight distribution between the front wheel and the rear wheel, as it is presented in the Figure 4.14.

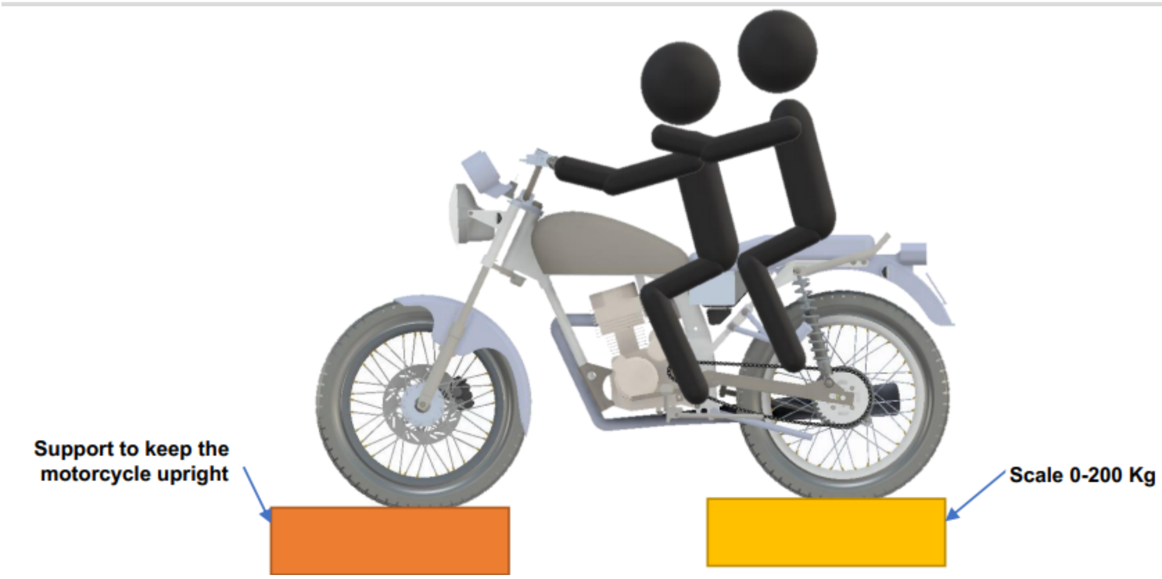


Figure 4.14: The measurement of the normal of the rear wheel of the motorcycle.

Figure 4.15 presents the different conditions applied to determine the normal force. For condition "1" an average value of 88.66 Kgf was obtained, for condition "2" an average value of 154.57 Kgf was obtained, and, for the last condition an average value of 184.71 Kgf was obtained.

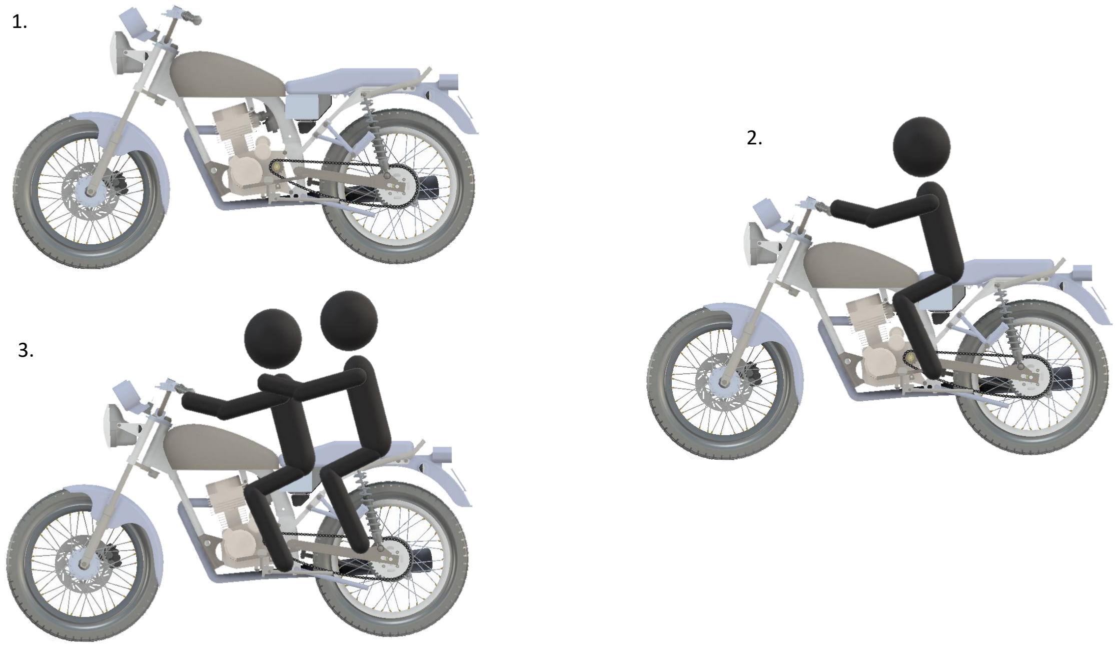


Figure 4.15: The ways in which the rear wheel normal of the motorcycle was measured.

The sum of forces in the different axes and of moments, with their respective values derived from the DCL illustrated in Figure.4.12, are presented next.

$$
\begin{gathered}
F_m = F_{m1} + F_{m2} \\
\Sigma F_x = F_m - R_{x1} - R_{x2} \\
\Sigma F_y = R_{y2} + R_{y1} - w_1 - w_2 - w_{eje} \\
\Sigma M_{A_x} = (0.0664m) * w_2 + (0.12018m) * w_{eje} + (0.1528m) * w_1 - (0.275) * R_{y2} \\
\Sigma M_{A_y} = (0.0664m) * F_{m2} + (0.1528m) * F_{m1} - (0.275m) * R_{x2} \\
\Sigma M_{A_z} = M_{R1} + M_{R2} + (0.006m) * (R_{x1} + R_{x2})
\end{gathered}
\tag{4.8}
$$

The values obtained for these forces are presented in the Table 4.10.

Table 4.10: Values of forces found after static analysis for the shaft.

Variable	**Value**	**Unit**
F_{m1}	743,1164	N
F_{m2}	743,1164	N
w_1	84,4089	N
w_2	84,4089	N
w_{eje}	9,8	N
F_m	1486,2328	N
Ry_2	71,564345	N
Ry_1	107,053455	N
Rx_2	592,331327	N
Rx_1	893,901473	N
M_{RT}	-8,9173968	Nm
$w_1 + w_2$	168,8178	N

Equation 4.9 shows the static equations that allow finding the values of the swing arm reactions.

$$\begin{gathered}\Sigma R_x = F_r + F_a * sin(\alpha) - R_{x1} - R_{x2} = 0 \\ \Sigma R_y = W - F_a * cos(\alpha) - F_n - R_{y1} - R_{y2} = 0 \\ F_a = 600N + K * x = 1994.4072N \\ Fr = 0.03 * Fn \\ \alpha = 24^\circ\end{gathered} \tag{4.9}$$

The values obtained for these equations are presented in the Table 4.11.

Table 4.11: Force values found in the static analysis for the swing arm s.

Variable	**Value**	**Unit**
Fa	1994,4072	N
Fn	1810,158	N
Fr	54,30474	N
Ry	-1803,9594	N
Rx	865,50323	N

The values obtained for R_y and R_x were -1803.9594 N and 865.5032 N, respectively. The K value, of the damper, is 22859.1348 N/m and it was obtained from the data, of the Figure 4.16, obtained from laboratory tests carried out at EAFIT University. The test was performed using the INSTRON 3366 machine with a preload for the damper of 600 N.

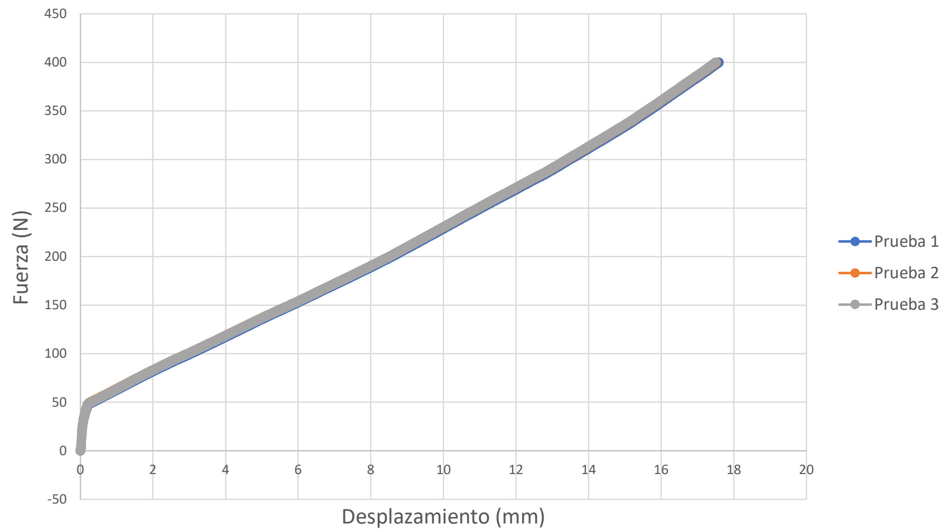


Figure 4.16: Data collected during testing for the shock absorber.

Finally, the values of the loads supported by the rear system in relation to the other mechanical systems of the motorcycle are found.

4.5.3 Static analysis of the sprocket

The free body diagram of the sprocket is presented in the Figure 4.17, in order to continue with the static analysis applying the equations 4.10, 4.11, 4.12, and 4.13.

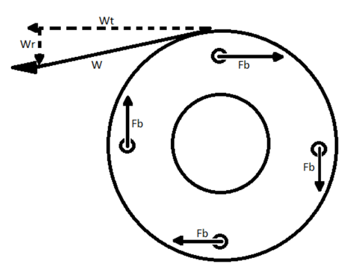


Figure 4.17: Sprocket free body diagram

$$W = \sqrt{(Wt)^2 + (Wr)^2} \quad (4.10)$$

$$Wt = \frac{Torque_{Wheel}}{(D/2)} \quad (4.11)$$

$$Wr = W * sen\alpha \quad (4.12)$$

$$4 * Fb * R = Torque_{motor} \tag{4.13}$$

Where Fb = Strength of sprocket bushings, R = Sprocket bushing radius, and D = Sprocket diameter

From the equation 4.4 the maximum torque that the coupling must support is 351 Nm. With this data and the forces in X and Y, it is calculated that $Wt = 3.7KN$, Wr is not taken into account, because the angle α is zero, since the force exerted by the chain is totally horizontal, sometimes it may have a deviation but this is considered negligible.

After obtaining the dynamic load supported by the clutch, how many cycles the clutch bearings can last in good condition is calculated, that is, before their replacement.

For this the equation 4.14 allows to calculate the basic nominal life for a bearing.

$$L = L1 * (\frac{Cr}{Pr})^{3.33} \tag{4.14}$$

For the data of the case study $L = 265 * 10^6$ cycles, and if this cycles are multiplied by the diameter of the wheel it is obtained that the life of the bearing is for 485.000 km.

This leads to the conclusion that the deep groove ball bearing on the clutch fixed shaft will need maintenance in 485,000 km, which means that with an estimated average use of 20,000 km/year (average use taken from the manufacturers' warranty estimates Motos (2020)), a component life of at least 24 years is expected.

With respect to the ratchet bearing by applying the same equation, it is found that $L = 117 * 10^6$ cycles, and a life of 426.376 km.

This leads to the conclusion that the ratchet bearing on the clutch housing shaft will require maintenance in 426,000 km, which means, with an estimated average usage of 20,000 km/year (average usage taken from manufacturers' warranty estimates Motos (2020)), a component life of at least 21 years is expected.

With these data found, the stress analysis on the cover of the designed coupling system follows next, in order to define the manufacturing process and the material.

4.5.4 Analysis of stresses in the casing

In order to perform a stress analysis, the SOLID EDGE program is used, where finite element analysis (FEA) simulations can be performed, especially on the coupling system designed, since this system relates and joins the operation of the ICE and the EM.

For all simulations, the eight holes through which the bolts are assembled to the engine cover were fixed and a pin-type restraint was used in the space where the ball bearing is located at the rear of the cover, and for all simulations a force of $17550N$ (equivalent to a torque of $351Nm$ applied to the cover, due to the action of the combustion engine and the chain in this area) was applied to one of the side faces of the wedge, which has a depth of $2.5mm$.

With the value of torque and tangential force found in the previous analysis, a stress analysis was made in the cover that will support and transfer the greatest load. In order to reduce the stresses in the area of intersection of the cover and the ratchet, the shape of the wedge and its depth are varied so that when choosing the material it is not of high cost and can have an acceptable safety factor.

Figure 4.18 presents the simulation result for the circular keyed cap applying the same constraints and forces as in the previous case, and an enlargement in the detail of the wedge to easily observe where the highest stresses are located or concentrated. These were presented in the rounding angle change with a maximum value of $1297MPa$.

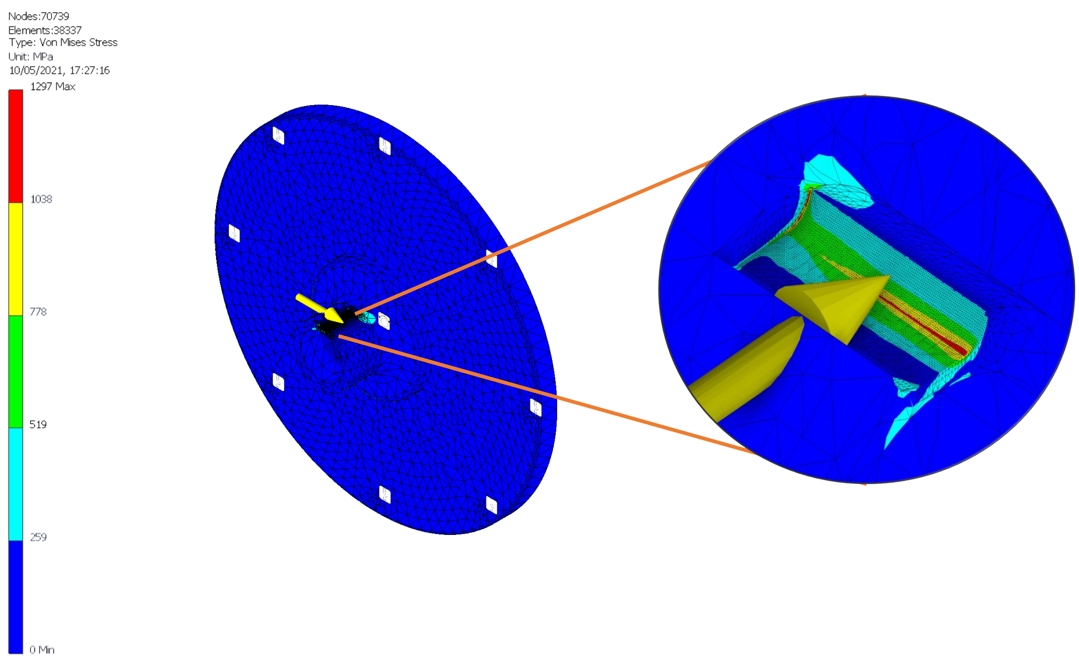


Figure 4.18: Circular Wedge Motor Cover

Similarly, Figure4.19 presents the results of the stress state with the trapezoidal wedge. In this case the stresses are concentrated in a line at very specific points at the junction between the flat horizontal face of the wedge and the lateral diagonal face of the wedge, obtaining a maximum stress value of $2825MPa$.

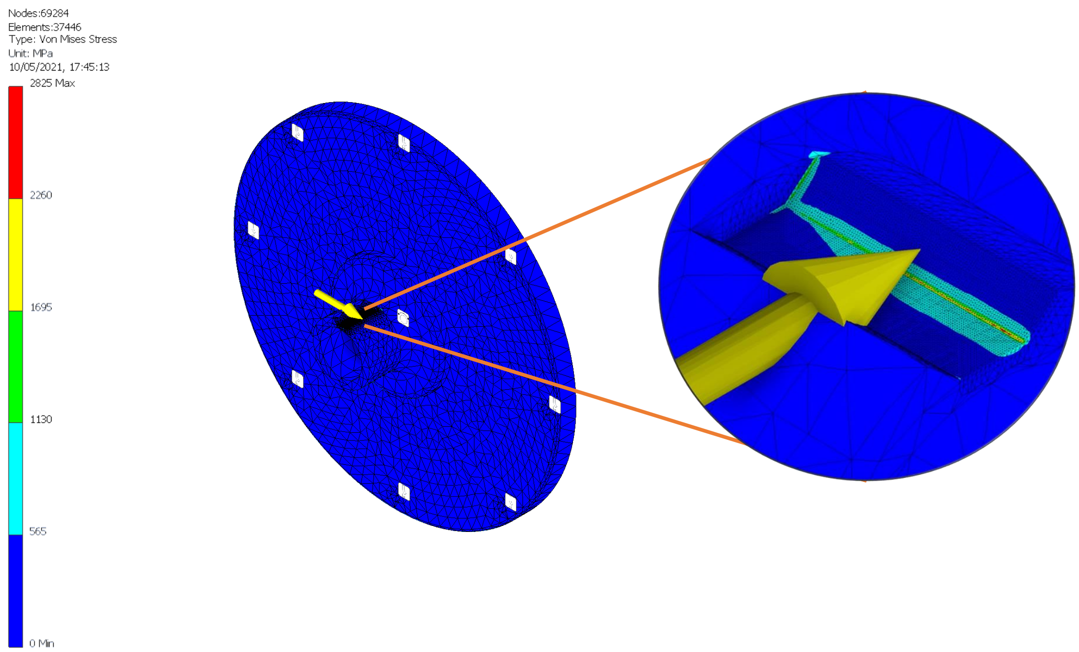


Figure 4.19: Trapezoidal Wedge Motor Cover

Finally, the Figure4.20 presents the results of the rectangular-shaped (conventional) keyed cover, and, similarly to the trapezoidal key, it shows stresses concentrated in specific areas with a higher value of 3049MPa.

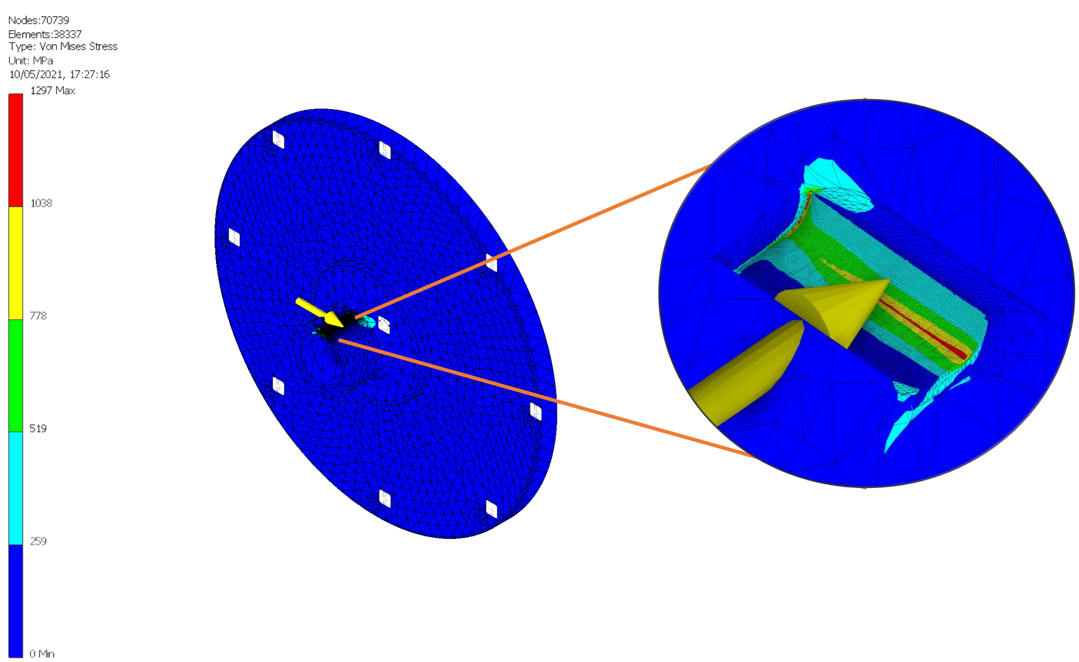


Figure 4.20: Rectangular Wedge Motor Cover

The Table 4.12 summarizes the various iterations and results were obtained by varying the depth of the wedge in the cap that joins the ICE with the EM.

Depth (mm)	**Rectangular (MPa)**	**Trapezoidal (MPa)**	Circular (MPa)
1	1336	853,6	775,7
1,25	1202	927,6	787,4
1,5	1191	968,9	820,1
1,75	1197	1011	865,1
2	1237	1105	964,9
2,25	1250	1189	1010
2,5	1352	1333	1093
2,75	1416	1426	1216
3	1404	1597	1371
3,25	1545	1898	1569
3,5	1620	2276	2020

Table 4.12: Stresses by wedge shape

It is concluded that the trapezoidal shape shows better results in stress reduction, but at the time of manufacturing, this can be complex,so at the manufacturing stage it is either affirmed or discarded.

4.5.5 Materials

Based on the above results, an evaluation of materials that in their mechanical and physical property ranges are capable of withstanding the maximum stresses of each scenario analyzed is carried out, taking as a reference mainly the yield stress and ultimate stress limits.

Table 4.13 presents properties of mostly steels, although it is found that 6000 series aluminum, which could represent a significantly high cost, keeps the weight of the motor cover low.

Table 4.13: List of materials for the manufacture of the Motor Cover

Material	Yield stress (Mpa)	Ultimate Limit (Mpa)	Maximum elongation (breakage)	Additional Processes
AISI 4053	1538	1724	12%	None
AISI 4063	1593	1855	8%	None
AISI 4130H 25mm	896	993	18,50%	Tempering (Water) 855 ºC, Caliber 25 mm
AISI 4130 H 50 mm	685	841	21,20%	Tempering (Water) 855ºC, Caliber 50 mm
AISI 4130 H 100 mm	635	800	21,50%	Tempering (Water) 855ºC, Caliber 100 mm
AISI 4140 13 mm	675	1020	17,80%	Normalized a 870ºC, air-cooled, Caliber 13 mm
AISI 4140 50 mm	635	972	16,50%	Normalized a 870ºC, air-cooled, Caliber 50 mm
AISI 4140 oil 13 mm	1110	1185	15,40%	Tempering (oil), Caliber 13 mm
AISI 4140H	655	1020	17,70%	Normalized a 870ºC
AISI 4150	740	1160	11,70%	Normalized a 870ºC
AISI 4150H	740	1160	11,70%	Normalized a 870ºC
AISI 4337	965	1448	N/D	None
AISI 4620 13 mm	620	876	20%	carburized, Tempering 150 ºC, Caliber 13 mm
AISI 4640	1103	1276	14%	None
AISI 4817	1795	N/D	N/D	None
AISI 4340	862	1282	12,2	None
AISI 1045	620	690	12	cold working, without preload
AISI 1045 Hardness 450HB	1069	1584	N/D	Hardness 450 HB
AISI 1045 Hardness 500HB	1259	1825	N/D	Hardness 500HB
AISI 1045 Hardness 595HB	1259	1825	N/D	Hardness 595HB
AISI 1045 Hardness 390HB	842	1343	N/D	Hardness 390HB

The materials that support the stresses produced by the determined load are: AISI 4053, AISI 4063, AISI 4140, AISI 4337, AISI 4640, AISI 4817, AISI 4340 AND AISI 1045, which will be considered for material selection.

The following characteristics were taken into account for material selection:

- Mechanical properties: hardness, elasticity, plasticity and fatigue.
- Physical properties: Density and corrosion resistance.
- Technological: Mechanization, maintainability and ductility.
- Environmental: Recyclability, reusability, toxicity and biodegradability.
- Cost and marketability.

4.5.6 Manufacturing

Figure 4.21 summarizes the manufacturing processes for the sprocket holder (taking into account that its shape is predominantly cylindrical). The recommended processes are casting, forging, machining and extrusion, depending on the degree of industrialization expected to be achieved with the hybridization kit.

Ability of Manufacturing Processes to Produce Shapes in Fig. 13.6

Process	Capability for producing shapes
Casting processes	
Sand casting	Can make all shapes
Plaster casting	Can make all shapes
Investment casting	Can make all shapes
Permanent mold	Can make all shapes except T3, T5; F5; U1, U5, U7
Die casting	Same as permanent mold casting
Deformation processes	
Open-die forging	Best for R0 to R3; all B shapes; T1; F0; Sp6
Hot impression die forging	Best for all R, B, and S shapes; T1, T2; Sp
Hot extrusion	All 0 shapes
Cold forging/ cold extrusion	Same as hot die forging or extrusion
Shape drawing	All 0 shapes
Shape rolling	All 0 shapes
Sheet-metal working processes	
Blanking	F0 to F2; T7
Bending	R3; B3; S0, S2, S7; T3; F3, F6,
Stretching	F4; S7
Deep drawing	T4; F4, F7
Spinning	T1, T2, T4, T6; F4, F5
Polymer processes	
Extrusion	All 0 shapes
Injection molding	Can make all shapes with proper coring
Compression molding	All shapes except T3, T5, T6, F5, U4
Sheet thermoforming	T4, F4, F7, S5
Powder metallurgy processes	
Cold press and sinter	All shapes except S3, T2, T3, T5, T6, F3, F5, all U shapes
Hot isostatic pressing	All shapes except T5 and F5
Powder injection molding	All shapes except T5, F5, U1, U4
PM forging	Same shape restrictions as cold press and sinter
Machining processes	
Lathe turning	R0, R1, R2, R7; T0, T1, T2; Sp1, Sp6; U1, U2
Drilling	T0, T6
Milling	All B, S, SS shapes; F0 to F4; F6, F7, U7
Grinding	Same as turning and milling
Honing, lapping	R0 to R2; B0 to B2; B7; T0 to T2, T4 to T7; F0 to F2; Sp

Figure 4.21: Manufacturing processes according to the form obtained from Dieter and Schmidt (1967)

Figure 4.22 relates the manufacturing process to the material to be worked and the quantity of units. It is considered a quantity from 1 to 100 and the chosen material is STEEL, as it was defined in the material selection stage. The recommended processes are: Casting, machining and spinning.

MATERIAL / QUANTITY	IRONS	STEEL (carbon)	STEEL (tool, alloy)	STAINLESS STEEL	COPPER & ALLOYS	ALUMINIUM & ALLOYS	MAGNESIUM & ALLOYS
VERY LOW 1 TO 100	[1.5] [1.6] [1.7] [4.M]	[1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1] [1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[1.6] [1.7] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.5] [1.7] [3.6] [4.M] [5.1]	[1.5] [1.7] [3.7] [3.10] [4.M] [5.5]	[1.6] [1.7] [3.10] [4.M] [5.1][5.5]
LOW 100 TO 1,000	[1.2] [1.5] [1.6] [1.7] [4.M] [5.3] [5.4]	[1.2] [1.6] [1.7] [1.10] [4.M] [5.1] [5.3] [5.4] [5.5]	[1.1] [1.2] [1.7] [4.M] [5.1] [5.3] [5.4] [5.5] [5.6] [5.7]	[1.2] [1.7] [3.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5]	[1.2] [1.3] [1.5] [1.7] [1.8] [3.3] [3.6] [4.M] [5.1] [5.3] [5.4]	[1.2] [1.5] [1.7] [1.8] [3.7] [3.10] [4.M] [5.3] [5.4] [5.5]	[1.6] [1.7] [1.8] [3.10] [4.M] [5.5]
LOW TO MEDIUM 1,000 TO 10,000	[1.2] [1.3] [1.5] [1.6] [1.7] [3.11] [4.A] [5.2]	[1.2] [1.3] [1.5] [1.7] [3.1] [3.3] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4] [5.5]	[1.2] [1.5] [1.7] [3.1] [3.4] [3.11] [4.A] [5.2] [5.3] [5.4] [5.5]	[1.2] [1.5] [1.7] [3.1] [3.2] [3.7] [3.10] [3.11] [4.A.] [5.2] [5.3] [5.4] [6.0]	[1.2] [1.3] [1.5] [1.8] [3.1] [3.2] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4]	[1.2] [1.3] [1.4] [1.5] [3.1] [3.3] [3.7] [3.10] [3.11] [4.A] [5.3] [5.4] [5.5]	[1.3] [1.5] [1.8] [3.1] [3.3] [3.4] [3.10] [4.A] [5.5]
MEDIUM TO HIGH 10,000 TO 100,000	[1.2] [1.3] [3.11] [4.A]	[1.0] [2.1] [3.0] [3.4] [3.5] [3.11] [3.12] [4.A] [5.2] [5.5]	[3.1] [3.4] [3.5] [3.11] [3.12] [4.A] [5.2]	[1.0] [3.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A]	[1.2] [1.4] [1.0] [3.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A]	[1.2] [1.3] [1.4] [1.8] [3.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A] [5.5]	[1.3] [1.4] [3.1] [3.3] [3.4] [3.5] [3.12] 4.A]
HIGH 100.000+	[1.2] [1.3] [3.11] [4.A]	[1.9] [3.1] [3.2] [3.3] [3.4] [3.5] [3.12] [4.A]	[4.A]	[1.9] [3.2] [3.3] [4.A]	[1.2] [1.M] [3.1] [3.2] [3.3] [3.4] [3.5] [3.7] [3.0] [3.11] [3.12] [4.A]	[1.2] [1.3] [1.4] [1.6] [3.1] [3.2] [3.3] [3.4] [3.5] [3.8] [3.12] [4.A]	[1.3] [1.4] [3.1] [3.3] [3.4] [3.0] [3.12] [4.A]
ALL QUANTITIES	[1.1]	[1.1] [1.5] [3.0] [3.0] [3.0]	[1.6] [3.6]	[1.1] [1.6] [3.6] [3.8] [3.9]	[1.1] [1.6] [3.6] [3.8] [3.9] 5.5]	[1.1] [1.6] [3.4] [3.5] [3.6]	[1.1] [3.5] [3.6] [3.8]

MATERIAL / QUANTITY	ZINC & ALLOYS	TIN & ALLOYS	LEAD & ALLOYS	NICKEL & ALLOYS	TITANIUM & ALLOYS	THERMOPLASTICS	THERMOSETS	FR COMPOSITES	CERAMICS	REFRACTORY METALS	PRECIOUS METALS
VERY LOW 1 TO 100	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [3.10] [4.M] [5.5]	[1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1] [1.6] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[2.5] [2.7]	[2.5] [3.7]	[2.2] [2.6] [5.7]	[1.5] [5.1] [5.5] [5.6] [5.7]	[1.1] [5.7]	[5.5]
LOW 100 TO 1,000	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.8] [3.10] [4.M] [5.5]	[1.2] [1.5] [1.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5] [5.6]	[1.1] [1.6] [3.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5] [5.6] [5.7]	[2.3] [2.5] [2.7]	[2.2] [2.3]	[2.2] [2.3] [2.6] [5.7]	[5.1] [5.3] [5.5] [5.6] [5.7]	[5.7]	[5.5]
LOW TO MEDIUM 1,000 TO 10,000	[1.3] [1.8] [3.3] [3.10] [4.A] [5.5]	[1.3] [1.5] [3.2] [3.10]	[1.3] [1.5] [3.3] [3.10]	[1.2] [1.3] [1.5] [1.7] [3.1] [3.2] [3.11] [4.A] [5.1] [5.3] [5.4] [5.5] [3.10]	[3.1] [3.7] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4] [5.5]	[2.3] [2.5] [2.6] [2.7]	[2.2] [2.3] [2.4]	[2.1] [2.2] [2.3]	[5.2] [5.3] [5.4] [5.5]		[5.5]
MEDIUM TO HIGH 10,000 TO 100,000	[1.3] [1.4] [3.3] [3.4] [3.5] [3.12] [4.A]	[1.3] [1.4] [3.3] [3.4] [3.12]	[1.3] [1.4] [3.3] [3.4] [3.8] [3.12] [4.A]	[3.1] [3.3] [3.5] [3.4] [3.11] [3.12] [4.A] [5.2] [5.5]	[3.1] [3.4] [3.11] [3.12] [4.A] [5.2] [5.5]	[2.1] [2.3] [2.6] [2.7] [2.8]	[2.1] [2.3] [2.9]	[2.1] [2.3]	[3.11]	[3.12]	[3.5]
HIGH 100.000+	[1.4] [3.2] [3.3] [3.4] [3.5] [4.A]	[1.4] [3.3] [3.4] [4.A]	[1.4] [3.2] [3.3] [3.4] [4.A]	[3.2] [3.3] [4.A]	[4.A]	[2.1] [2.6] [2.0]	[2.1] [2.3] [2.4] [2.9]		[3.7] [3.11]		[3.5]
ALL QUANTITIES	[3.6] [3.8] [3.9]		[3.5]	[1.1] [1.6] [3.4] [3.5] [3.8]	[3.8] [3.9]				[5.5]	[1.5]	[1.6]

KEY TO MANUFACTURING PROCESS PRIMA SELECTION MATRIX:

CASTING PROCESSES
- [1.1] SAND CASTING
- [1.2] SHELL MOULDING
- [1.3] GRAVITY DIE CASTING
- [1.4] PRESSURE DIE CASTING
- [1.5] CENTRIFUGAL CASTING
- [1.6] INVESTMENT CASTING
- [1.7] CERAMIC MOULD CASTING
- [1.8] PLASTER MOULD CASTING
- [1.9] SQUEEZE CASTING

PLASTIC & COMPOSITE PROCESSING
- [2.1] INJECTION MOULDING
- [2.2] REACTION INJECTION MOULDING
- [2.3] COMPRESSION MOULDING
- [2.4] TRANSFER MOULDING
- [2.5] VACUUM MOULDING
- [2.6] BLOW MOULDING
- [2.7] ROTATIONAL MOULDING
- [2.8] CONTACT MOULDING
- [2.9] CONTINUOUS EXTRUSION (PLASTICS)

FORMING PROCESSES
- [3.1] CLOSED DIE FORGING
- [3.2] ROLLING
- [3.3] DRAWING
- [3.4] COLD FORMING
- [3.5] COLD HEADING
- [3.6] SWAGING
- [3.7] SUPERPLASTIC FORMING
- [3.8] SHEET-METAL SHEARING
- [3.9] SHEET-METAL FORMING
- [3.10] SPINNING
- [3.11] POWDER METALLURGY
- [3.12] CONTINUOUS EXTRUSION (METALS)

MACHINING PROCESSES
- [4.A] AUTOMATIC MACHINING
- [4.M] MANUAL MACHINING

(THE ABOVE HEADINGS COVER A BROAD RANGE OF MACHINING PROCESSES AND LEVELS OF CONTROL TECHNOLOGY. FOR MORE DETAIL, THE READER IS REFERRED TO THE INDIVIDUAL PROCESSES.)

NTM PROCESSES
- [5.1] ELECTRICAL DISCHARGE MACHINING (EDM)
- [5.2] ELECTROCHEMICAL MACHINING (ECM)
- [5.3] ELECTRON BEAM MACHINING (EBM)
- [5.4] LASER BEAM MACHINING (LBM)
- [5.5] CHEMICAL MACHINING (CM)
- [5.6] ULTRASONIC MACHINING (USM)
- [5.7] ABRASIVE JET MACHINING (AJM)

Figure 4.22: Manufacturing processes according to the quantity obtained of Dieter and Schmidt (1967)

Finally, in the Figure4.23, the 3 categories: material, process and quantity of parts are considered altogether. It is found that casting, machining and forging are the most suitable processes for the needs presented.

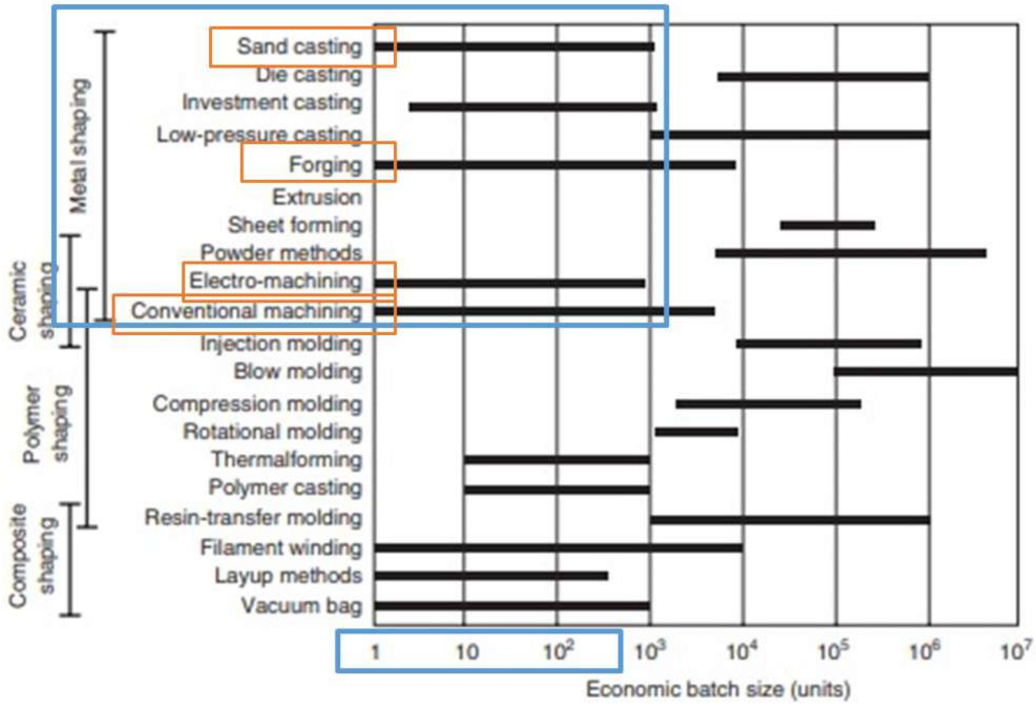


Figure 4.23: Manufacturing processes according to the material and units obtained from Dieter and Schmidt (1967)

The recommended processes for metals are Forging, casting, extrusion, machining, among others. Depending on the shape, finish, tolerances and the number of units to be produced, for this particular case is less than 10, conventional machining is selected, consequently, the necessary quotations to evaluate prices and manufacturing processes are required. These manufacturing processes apply to both the engine cover plate and the sprocket holder design.

4.5.7 Cost

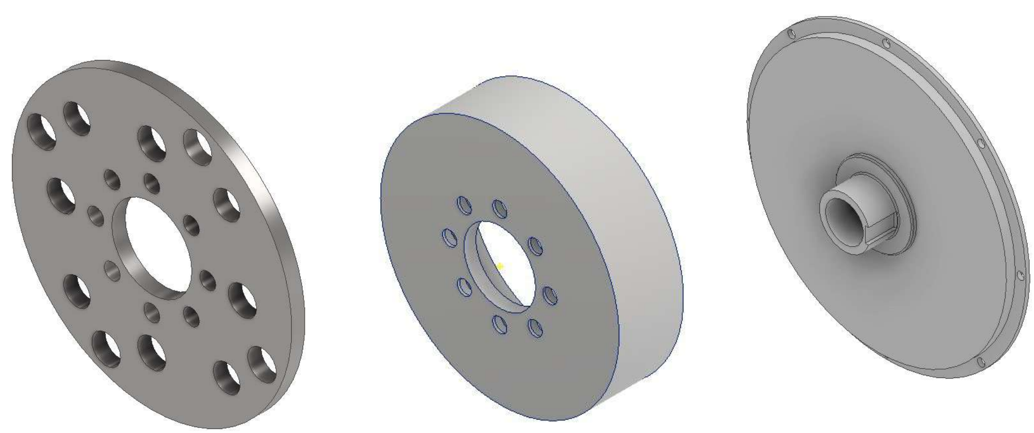
Although the materials shown in the Table 4.13 meet the necessary characteristics not all are readily commercially available, and some require highly specific post machining treatments (such as tempering, carburizing or cold forging), which could increase processing costs. For this reason, and based on the prices reported by the suppliers in the Table 4.14 for a 260mm diameter and 65mm long bar slice, it is decided to use the AISI 1045 material due to its relative low cost with respect to its mechanical properties and its good response to quenching processes.

Table 4.14: Table of prices of commercial materials.

Material	Ferroindustrial Price	Ferrocortes Price
AISI 1045	N/D	$287.980
AISI 4140	$339.000	$403.410
AISI 4340	$223.470	N/D

4.6 Stage 6. Prototyping.

In order to test the parts that are part of the coupling system, a CAD model is made, as it is shown in the Figure 4.24.



(a) Universal plate (b) Sprocket Holder (c) Engine cover

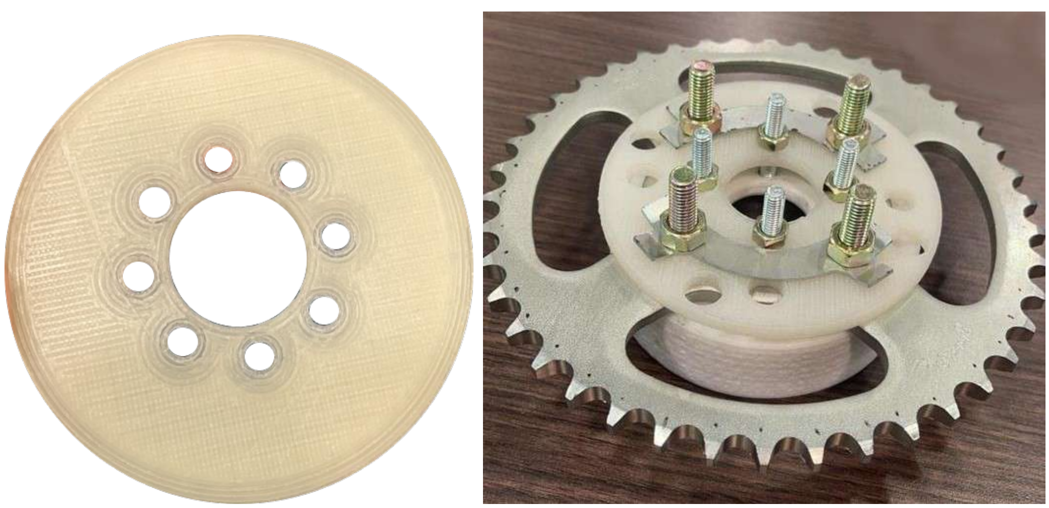
Figure 4.24: CAD models - Parts of the coupling system

Then, the 3D prototyping technique is used to materialize the designed parts, as it is shown in the Figures 4.25 and 4.26. The Figure 4.25 is the motor cover, responsible for covering the surface of the motor where the winding is located. It is joined by 8 screws and at the rear there is a cavity where the ball bearing is located that gives rotation to the cover. This has a protrusion that has a groove where the wedge is located and the inner race of the ratchet type bearing or one-way bearing is supported.

(a) Front view Engine cover (b) Rear view Engine cover

Figure 4.25: 3D Prototypes - engine cover

Then, the Figure 4.26 is the sprocket holder, responsible for housing the ratchet bearing, but its main contact is the outer track of this. It has 8 holes where M6 screws are located that hold the universal plate, this plate has the sole function of joining the sprocket with the sprocket holder.



(a) Engine cover (b) Universal plate and Sprocket Holder

Figure 4.26: 3D Prototypes - Sprocket holder.

Although 3D prototyping is a good solution to make a soft model of mechanical parts, in most cases very defined tolerances are needed, which prototyping in this way is not able to meet, so it was decided to manufacture in the material defined for the parts and set up the assembly for functional testing.

4.7 Stage 7. Functional validation.

In order to check the list obtained in the stage 3, the tests relevant to the specifications are presented in the Table 4.15.

	Check list of specifications		
1	Increase in total mass.	**17**	Intensity.
2	IP protection degree.	**18**	Modifications to the original motorcycle
3	Increase in total mass	**19**	Time required to install the kit.
4	Maximum width allowed.	**20**	Reduction of hydrocarbons per km.
5	Equivalent energy efficiency.	**21**	Carbon monoxide reduction per km.
6	Maximum torque	**22**	Specialized tools.
7	Maximum power	**23**	Center of gravity.
8	Volume occupied on the motorcycle.	**24**	Safety factor.
9	Maximum weight allowed.	**25**	Service life of mechanical components.
10	Maximum length allowed.	**26**	Time required to perform maintenance.
11	Maximum height allowed.	**27**	Service life of electrical machines.
12	Total value of the kit.	**28**	Specialized tools.
13	Equivalent energy efficiency.	**29**	Service life of main transmission and wear elements.
14	Maximum permissible wheelbase.	**30**	Time required to make a visual inspection.
15	Overall energy efficiency.	**31**	Service life of brake system wear elements.
16	Street motorcycle segment.		

Test
Water and dust proof.
Prototype measurements.
Street test with a controller to measure comparative variables.
Technical analysis stage 5.
Analysis stage 1.
Intensity test
Measuring time during assembly and disassembly

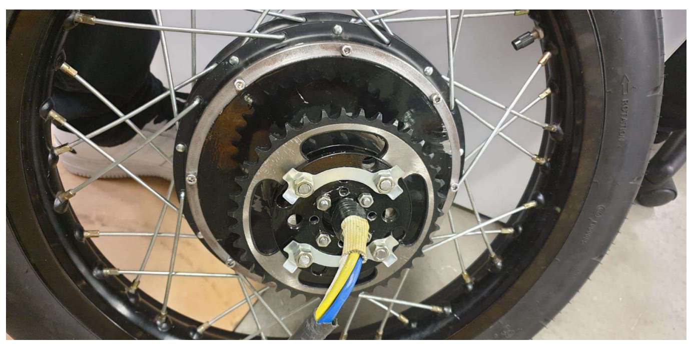
Table 4.15: Check the list of specifications by means of tests

First of all, to start the operation tests, the EM is incorporated to the wheel, by means of process of installing the spokes of the wheel, where the 36 spokes are installed from the rim to the EM, as it is shown in the Figure 4.27.

(a) Electric motor (b) Completed system

Figure 4.27: Electric motor with the spokes.

Then, the sprocket holder system is assembled, where first the screws are inserted inside the sprocket holder, then the ratchet bearing and the wedge corresponding to the external track are placed on top. Then, the sprocket is placed with the M6 screws of the sprocket holder and the universal plate is placed on top with the M8 screws on the front part of the sprocket holder. Finally, the motor cover is placed on the EM and screwed as it is shown in the Figure 4.28.



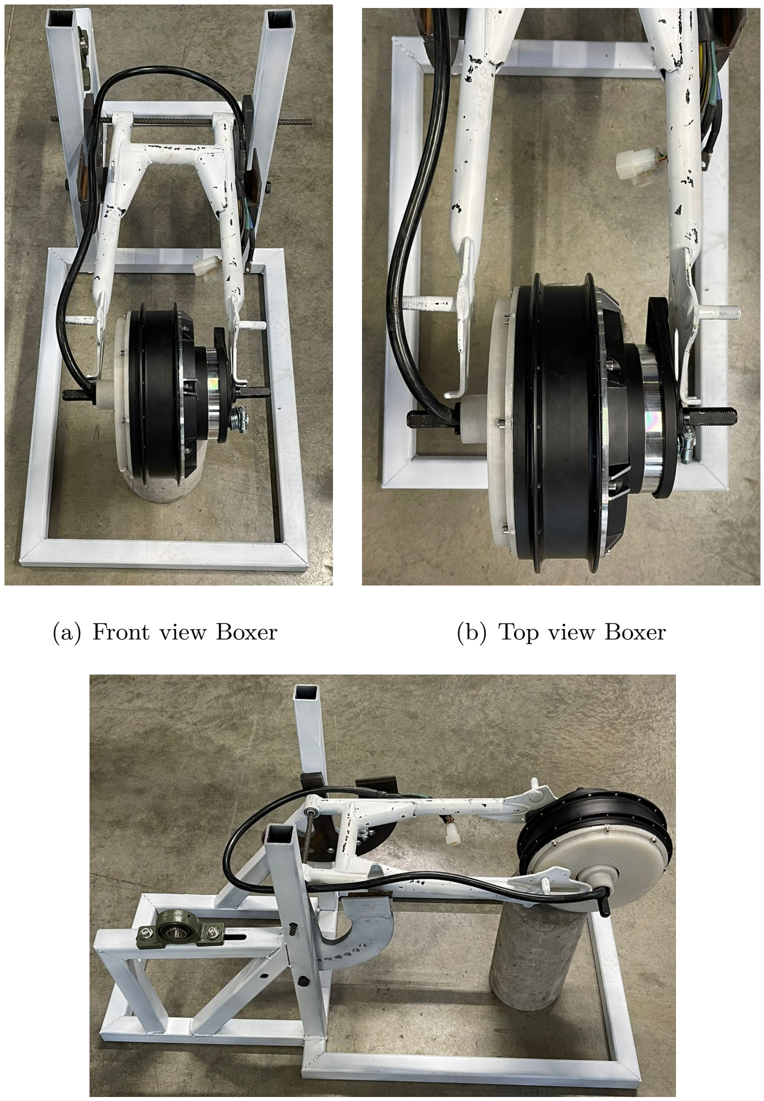
(a) Front view (b) Complete assembly

Figure 4.28: Mechanized coupling system

4.7.1 Testing on the BoxerCT100

This motorcycle reference has structural features in its power train that are different from all others, such as having the swing arm built with a circular profile, and the thickness varies along its length. The different swing arms have been tested in a bench test for the electric motor assembly. The Figure

4.29 presents the test for the Boxer, where its width is not enough for the shaft to slide and be supported within the mounting points. Due to this issue this electric motor reference could not be implemented for the Boxer CT100, which rules out the application in this motorcycle.



(a) Front view Boxer (b) Top view Boxer

(c) Lateral view Boxer

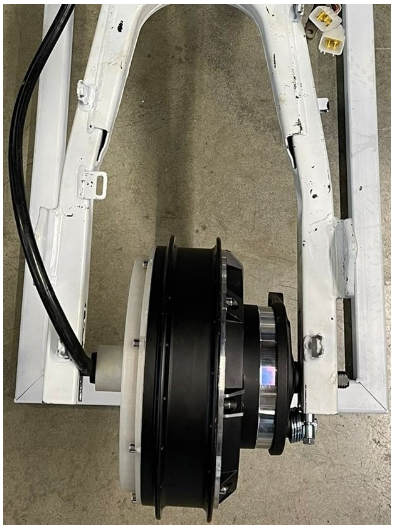
Figure 4.29: Bench mounting with Boxer CT100

4.7.2 Testing on the Discover 125

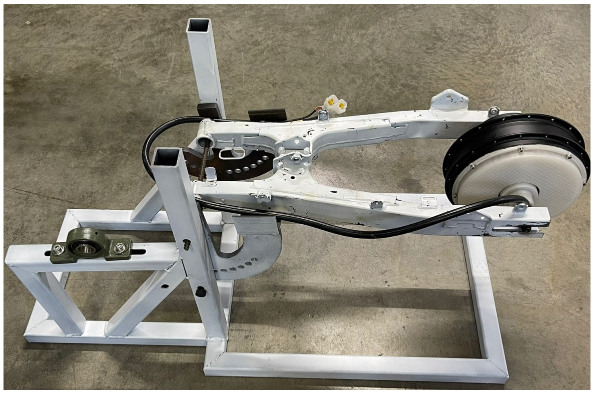
The Discover swing arm has a rectangular profile and, unlike the other bikes, its damping is mono shock, i.e. a single shock absorber in the central part of the seat post.

The Figure 4.30 presents the installation of the electric motor in the swing arm, and it is evident that the screw belonging to the drum brake of the electric motor collides with one side of the swing arm and restricts the movement of the motor. In this way the axis has a longer side with respect to the middle plane of the swing arm. Also, the protruding cable has limited space for its mobility.

(a) Front view Discover



(b) Top view Discover



(c) Lateral view Discover

Figure 4.30: Bench mounting with Discover

It is also concluded that the motor is not completely centered in space, i.e. it is not aligned with the center of the motorcycle.

4.7.3 Testing on the NKD 125

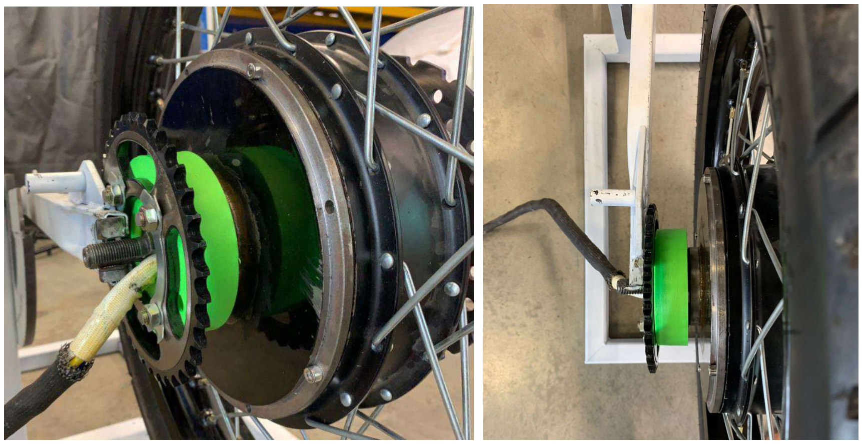
The electric motor in this reference slides and rests on the swing arm. It also allows to secure and fix it on each side, but the power cable is pressed more than in the Discover motorcycle with the side of the arm. Also, the motor is not centered or aligned with the central axis of the bike. On the other hand the drum brake screw is stuck with the swing arm and hinders the free movement of the electric motor. These aspects are presented in the Figures 4.31 and 4.32.

(a) Front view NKD125

(b) Top view NKD125

(c) Lateral view NKD125

Figure 4.31: Bench mounting with NKD125

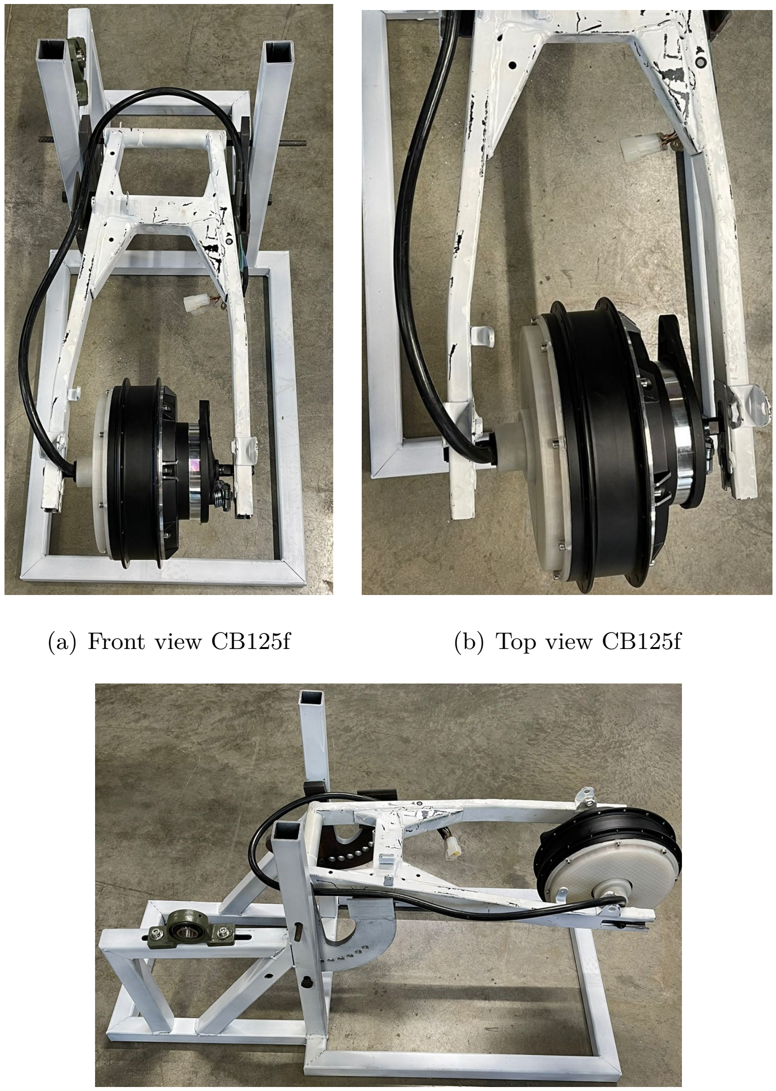


(a) Lateral view (b) top view

Figure 4.32: Coupling implemented in the NKD125 with disc brake.

4.7.4 Testing on the CB125f

The Figure 4.33 presents the test with the swing arm and the electric motor for the CB125f. The swing arm is a slim rectangular profile structure, has the connection points of the double shock absorber, and is the widest of all, so that the electric motor, although it is supported and the shaft is supported, does not protrude from the sides, which does not allow it to be fixed, and there would be no alignment with respect to the center of the motorcycle.



(a) Front view CB125f (b) Top view CB125f

(c) Lateral view CB125f

Figure 4.33: Bench mounting with CB125f

From the tests with the swing arms and the electric motor is concluded that the space occupied by the coupling system must be minimized in some selected references. For this there are several limitations that are the motor winding and bearings chosen for this system, because of this, it is decided to seek bearings that support the same dynamic and static load factor but with a less wide.

It is also found as mentioned that on the DISCOVER 125 and CB125f, an extension for the shaft is needed to solve the EM attachment on the swing arm.

4.8 Stage 8. Adjustments and improvements.

4.8.1 Solution situation 1: reduction of space in the coupling system

In order to define a bearing with smaller dimensions, a research has been carried out and the results are structured in the table 4.16.

Reference	Brand	Data C KN	Data (C_0) KN	Nominal life (Cycles)	Nominal life Km	Price 1	Price 2	Price 3
Bearing FAG (30X55X9)	FAG	11,2	7,35	27736323,61	101078,03	$30.165,31	$36.295,00	
Bearing NSK (30X42X7) VV o ZZ	NSK	4,7	3,65	2049691,035	7469,58	$50.216,81	$64.706,25	
Bearing NSK (30X47X9) VV o ZZ	NSK	7,25	5	7523308,096	27416,80	$34.175,61		
Bearing NSK (30X55X9) VV o ZZ	NSK	11,2	7,35	27736323,61	101078,03		$34.510,00	
Bearing KOYO (30X42X7)	KOYO	5,65	3,4	3560739,245	12976,22	$36.579,41	$49.980,00	$33.500,00
Bearing KOYO (30X47X9)	KOYO	9,05	5	14633242,35	53327,16		$46.410,00	$42.000,00
Bearing KOYO (30X55X9)	KOYO	14,1	7,35	55341657,95	201678,70	$22.644,51	$41.650,00	$25.000,00
Bearing ISB (30X55X9)	ISB	11,9	7,4	33268690,9	121239,34	$17.419,22		
Bearing EZO (30X47X9) VV o ZZ	EZO	7,2	5	7368724,459	26853,46	$31.385,06		

Table 4.16: Bearing table

The bearings were classified by brand, load factors, nominal life and sales prices; to select the bearing that would replace the previous one, mainly the nominal life in km and the price were reviewed. Considering that the measures were almost all the same, they were between 7 mm and 9 mm, but the 7 mm ones were discarded since both had a very low nominal life and would be parts of continuous change, which would not justify a maintenance review of a motorcycle.

Fulfilling the defined factors, the selected bearing is the KOYO reference 16006 (30X55X9). This bearing allows to reduce 4 mm of thickness in the motor cover. The drawings and design process of the redesigned cover are presented in the Appendix B. Also, a modification is made in the Sprocket Holder, eliminating the universal plate, and allowing the direct coupling to the sprocket.

The Figure 4.34 presents the result of these modifications to the system.

Figure 4.34: 3D printing of the Sprocket Holder - iteration 2

The Figure 4.35 shows how this solution allows the motor to enter completely into the swing arm of the NKD motorcycle, and, also, gives the alignment of the EM with the ICE.

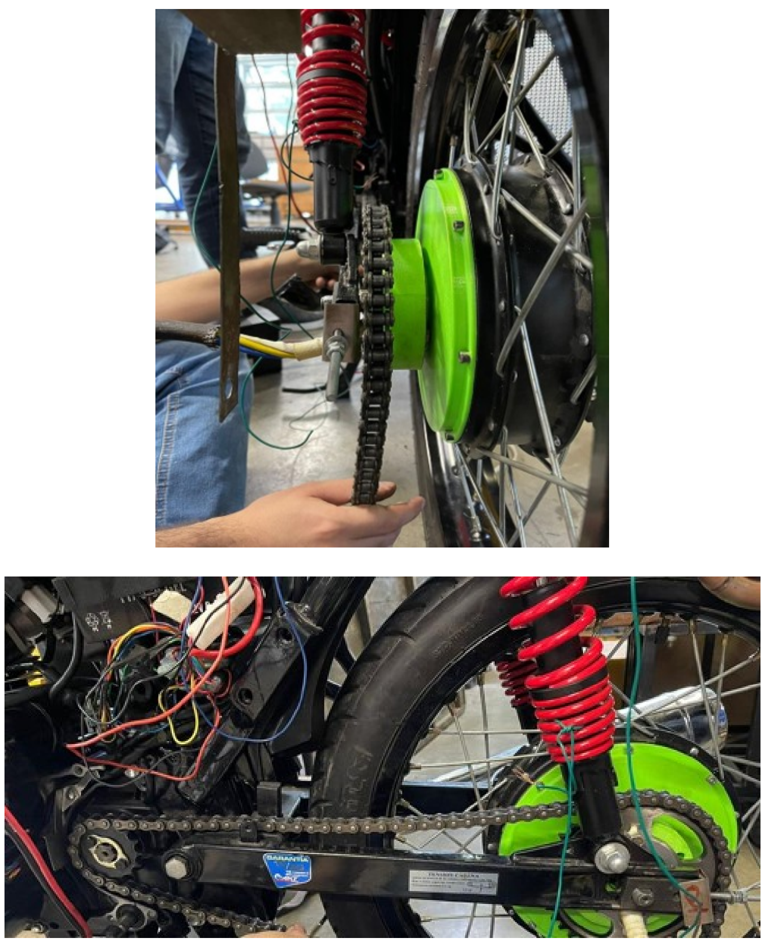
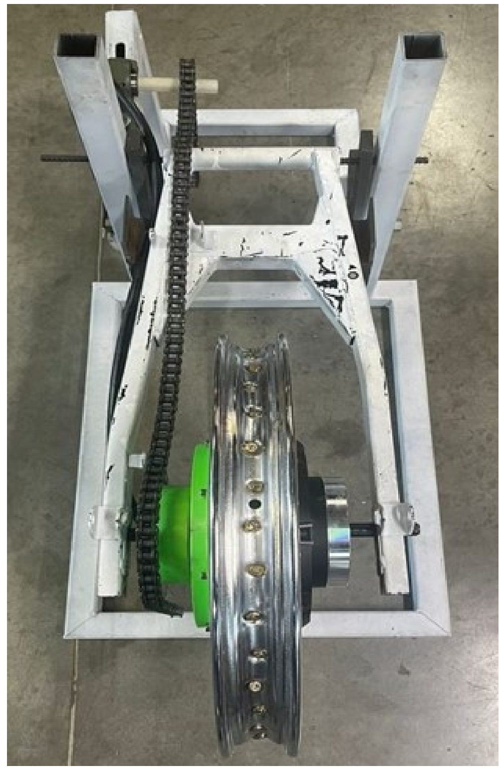


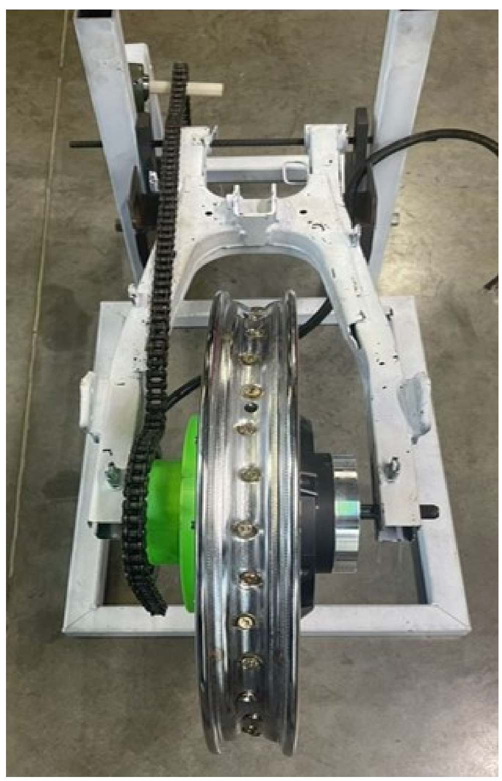
Figure 4.35: Functional tests in the NKD motorcycle

Since dimensional changes were made in the main design of the coupling system between the engines, the tests are repeated in all motorcycles, as it is shown in the Figure 4.36 and the Figure 4.37.

(a) NKD 125



(b) CB125F



(c) DISCOVER 125

Figure 4.36: Functional tests in the test bench

(a) NKD 125

(b) CB125F

(c) DISCOVER 125

Figure 4.37: Functional tests in the test bench 2

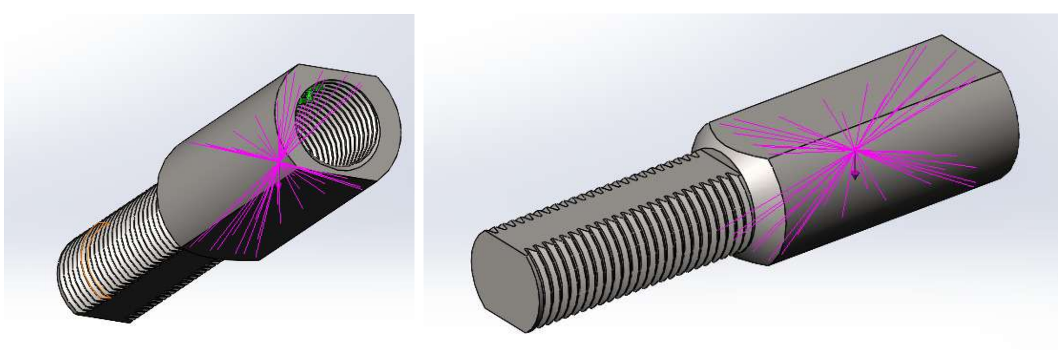
Regarding the Honda CB125f motorcycle, it is observed that the new coupling design fits perfectly in the swing arm space. When placing the chain it is evident that this passes in the line of the output sprocket, and with relevant installation adjustments, alignment can be achieved in this prototype. But, it is also observed that the EM is possible to fix it on one side and not on the other, i.e., on the side of the drum brake the shaft passes through the thickness of the swing arm but not on the other side. Then, it can be concluded that the centered motor has one side of the shaft longer than the other, and, with respect to the Bajaj Discover 125 bike, the same conclusion is obtained, with the difference that the thickness of this swing arm is greater than that of the CB125f, and also the space where the EM is located is smaller, so it restricts the movement to a greater extent.

It is concluded that with the corrections mentioned above, 3 motorcycle references fit perfectly on the corresponding swing arm in terms of EM width, and, also, give the alignment with the ICE output pinion.

4.8.2 Solution situation 2: Extension of the motor shaft.

In performing dimensional tests with the prototype coupling, it is evident that on the DISCOVER 125 and CB125f, one side of the motor shaft is too short, which prevents the EM from attaching to the swing arm.

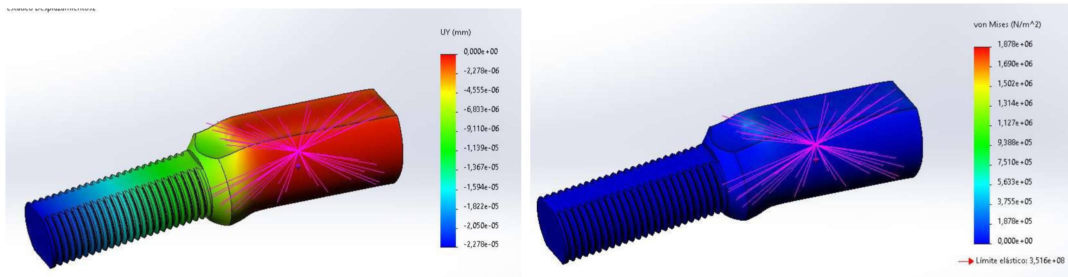
For this it is necessary to develop a piece that serves as an extension of the motor shaft, as shown in Figure 4.38, 2 designs were proposed, which differ in the contact area they have with the swing arm, as will be explained later.



(a) Front isometric view (b) Lateral isometric view

Figure 4.38: Load location for finite element simulation of the motor shaft extension.

The results of maximum deformation, and the corresponding stress state, are given in the Figure 4.39.

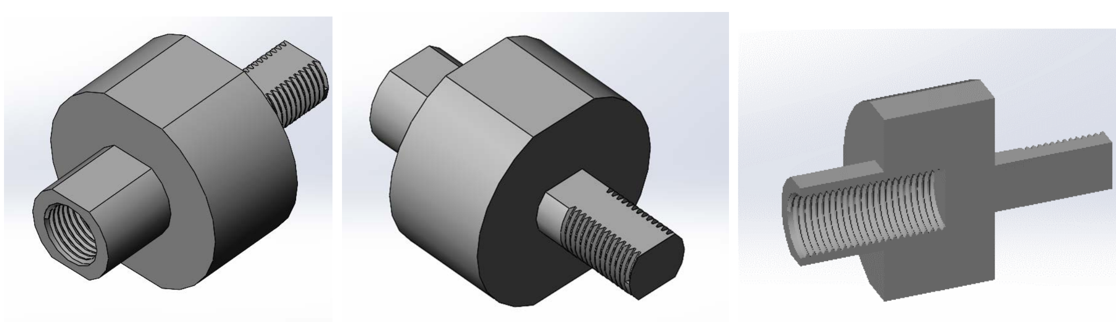


(a) Deformation results (b) Von Misses stress

Figure 4.39: Simulation of shaft extension iteration 1

It was necessary to increase the contact area of the extension piece with the swing arm slot (in order to increase the adjustment), because when installed on the test bench, the bushing presented clearance in the assembly. Also, this design was only supported on the lower faces of the slot causing a stress concentration in these points.

Since this bushing, as well as the swing arms, is critical for the user's safety, the aim is to increase the support area of the bushing in the rectangular profile of the swing arm. Then, a new design of a shaft extension is carried out, as it is shown in the Figure 4.40.



(a) Front isometric view (b) Rear isometric view (c) Longitudinal section view

Figure 4.40: Shaft extension iteration 2

This part allows a better positioning within the swing arm profile, providing more contact surface, and reducing the crushing stresses of the material.

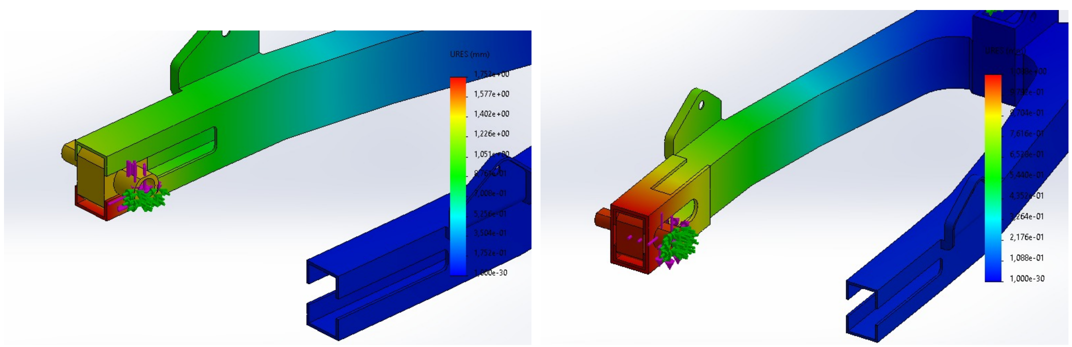
The simulation model involves the extension of the axle and the swing arm restraining the sides of the slot (cantilever), turning them into a rigid structure, in order to limit the deformations that can be caused by the resulting forces (inclination of the swing arm and displacement of the masses of the motorcycle, rider and passenger in the vertical direction).

The system is subjected to different external loads, including the weight of two persons. For this purpose, a system of reactions and forces is proposed (as it is shown in the stage 6), where from loads distributed on the rear wheel through axle of 1803.9596 N on the Y-axis and 865.50323N on the Z-axis, the following boundary conditions are proposed.

The force is divided in two, because the system will only be simulated on the output pinion side. Besides, to optimizing the speed and efficiency of the program, thereafter, a mobility constraint is presented along the Z and X axis, so that the swing arm only deforms vertically.

Also, constrained at the points of the motorcycle, suspension and, finally, at the cylindrical surfaces where the axle that holds the swingarm at the front would pass, allowing rotational mobility in the direction of the X-axis. This in order to give a simulation closer to reality of how the swing arms act.

The Figure 4.41 presents the results obtained with these boundary conditions, defining "no penetration" between parts.

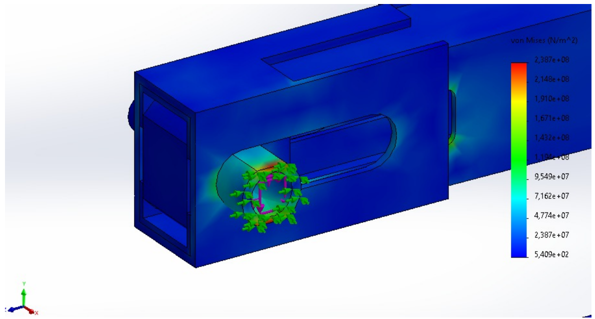


(a) Boundary conditions for swing arm without external cover (b) Boundary conditions for swing arm with external cover

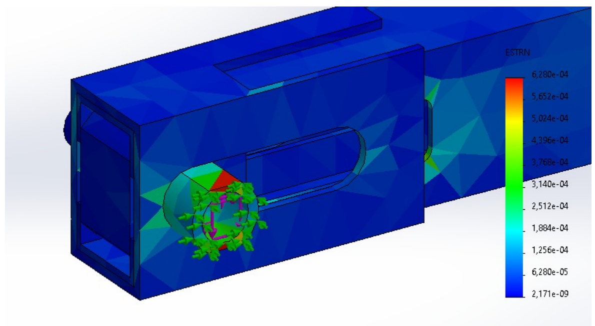
Figure 4.41: Initial swing arm simulation process

The system presents a maximum deformation of 1mm, and a maximum unit deformation of $6 \exp -4mm$. The swing arm is a critical piece, it must have a safety factor associated to the design and manufacture, and in the simulation a minimum safety factor FS=1.5 is obtained in the whole system.

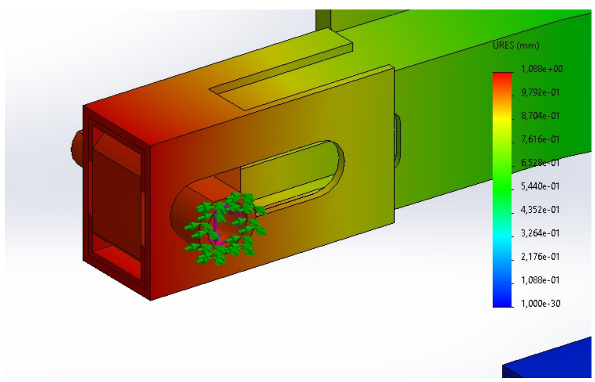
This concluded that the element does not fail and presents low deformations. Finally, analyzing the set of assembled parts, using the design tool, it is observed that the cover that was included in the model, does not have to completely cover the swing arm, since the system needs reinforcement at the beginning of the arm, where the critical points are shown. Therefore, with a less robust redesign, the same simulation results can be achieved.



(a) Analysis results Von mises method



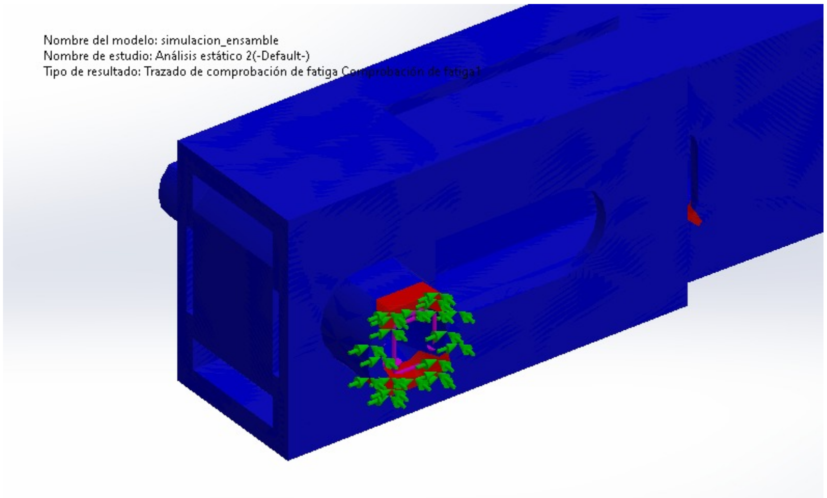
(b) State of unitary swing arm deformations



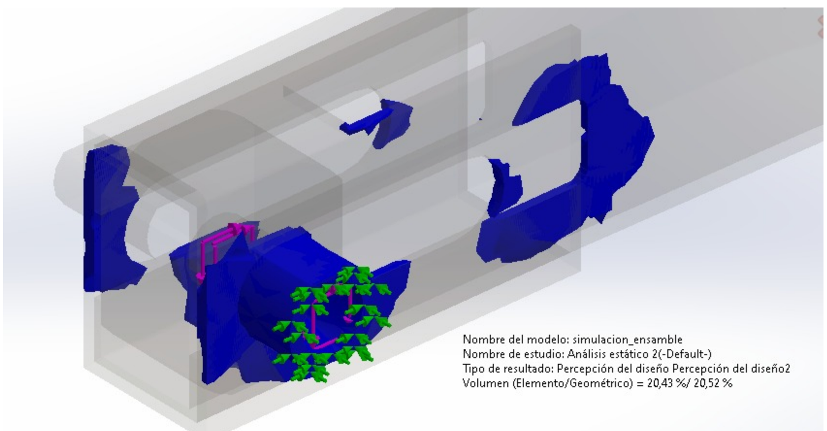
(c) Deformations resulting from the swing arm tip

Figure 4.42: Simulation results of swing arm tips.

In these results it is observed that both the swing arms and the cover do not present relevant deformations nor do they support most of the stresses, since the reaction forces are being restricted and applied in the extension of the EM shaft. Therefore, the design demonstrates safety for the user in addition to having maximum deformations of approximately $2e-4mm$,as it is observed in the Figures 4.42 and 4.43.



(a) Critical load conditions on shaft extension bushing



(b) Critical bearing points on swing arm

Figure 4.43: Check of critical points against the load condition of the swing arm and axle extender bushing.

Then, the axle extension is safe for the user and does not present high deformations or critical points for the normal operation of the motorcycle, and it can be manufactured in order to test it.

4.8.3 Shaft manufacturing and testing.

The first iteration of the shaft extension is presented in the Figure 4.44. This design has two flat faces that try to imitate the shape of the motor shaft, in a diameter of 20mm. Internally, it has a thread M16x1.5, which allows direct coupling to the shaft.

Figure 4.44: Iteration 1 of shaft extension bushing.

The second iteration of the shaft extension is presented in the Figure 4.45. This design has two flat faces with a diameter of 50 mm, in order to have more contact area inside the swing arm, that is, not only contact in the groove but also inside the profile of the swing arm. Internally, it has a thread M16x1.5 that allows direct coupling to the shaft.

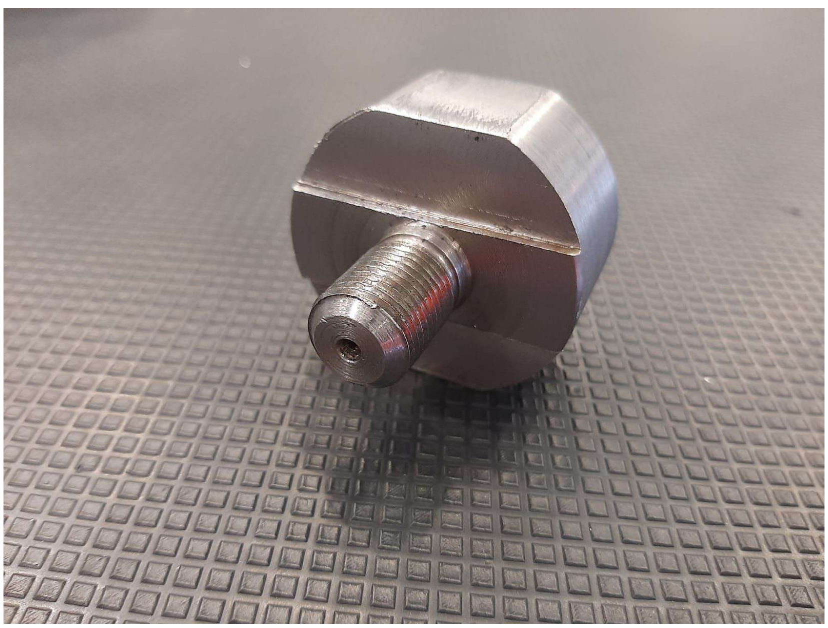


Figure 4.45: Iteration 12 of shaft extension bushing.

To perform the tests, each bushing was adapted to the motor shaft, as it is shown in the Figure4.46.

(a) Iteration 1 (b) Iteration 2

Figure 4.46: Shaft Extender Bushing Trial Installation

Both designs were installed in the swing arms as it is shown in the Figure 4.47.

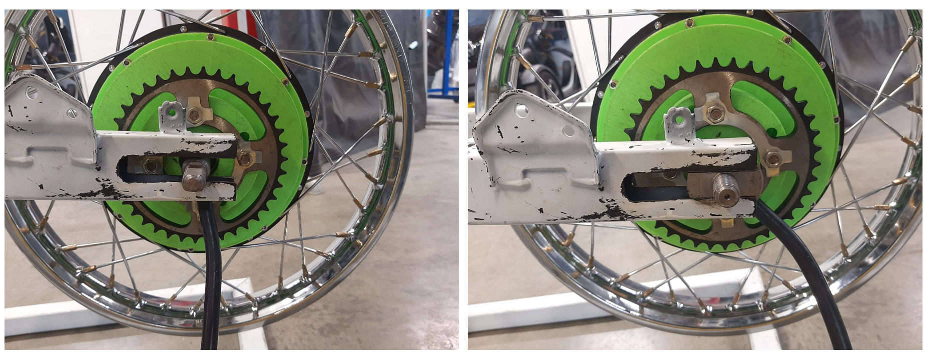
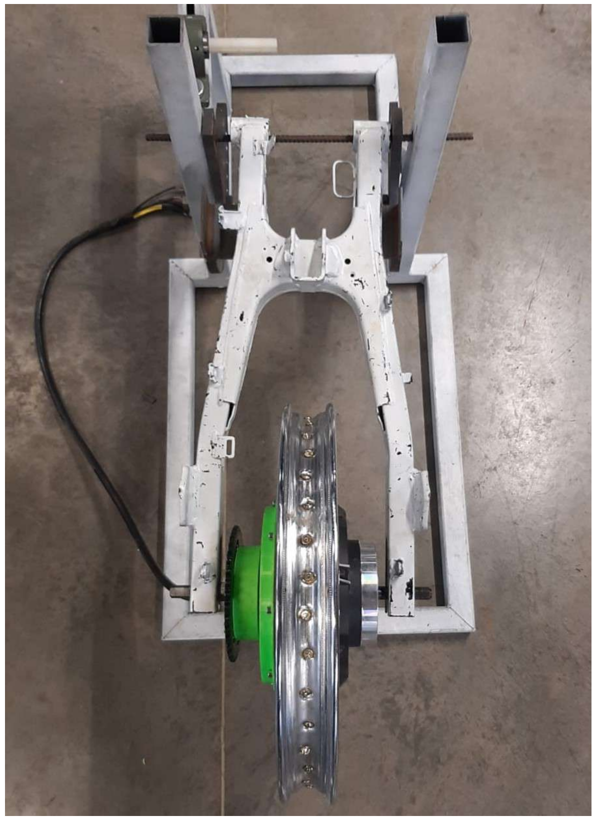


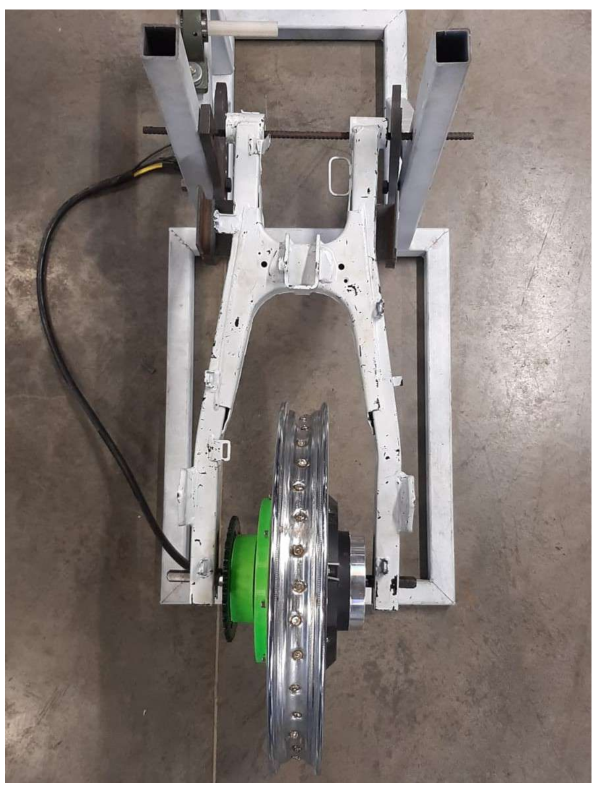
Figure 4.47: Implementation of ext. bushing - swinging arm test

Iteration 1 presents a poor tightening in relation to the profile of the swing arm due to its small contact area. On the other hand, iteration 2 does not present this problem, because it is supported in the groove and inside the swing arm, reducing the stresses that occur in the area.

Additionally, having the largest diameter, at the same time, it would be tensioner of the chain. Moreover, it is possible to tight the shaft on the shaft extender (which supports high compression), instead of the swing arm profile, which may suffer deformation due to this tightening. These advantages are observed in the Figure 4.48.



(a) Alignment iteration 1



(b) Alignment iteration 2

Figure 4.48: Alignment test

Applying the whole methodological process, the modification in the motorization of 3 of the 4 selected motorcycles is achieved, counting with processes of design of mechanical systems, redesign and standardization. All the developed parts are transverse to the motorcycles and their mechanical systems.

Chapter 5

Evaluation of the methodology

5.1 Evaluation approach

To carry out the evaluation of the methodology in a qualitative way, three evaluation teams were selected, composed of 7 people, the first T1, composed of people directly related to the project in which the methodology was implemented, that is the case study. The T2, composed of people who have knowledge about the research project but are not directly related to the case study. And, T3 composed of experts in the theoretical and practical area of the methodologies. All the evaluators are people who belong to the engineering area.

T1 is composed of mechanical engineering students and master degree students in engineering.

T2 is composed of master degree students in engineering and doctoral students in engineering.

T3 is composed of professors and engineering professionals who are experts in the application of research, design and work methodologies.

Each participant of the teams T1 and T2 was given a survey consisting of 21 questions with answers, yes, no, and maybe, all with their corresponding justification. The application Google forms was used. Also, a document with the methodology explained step by step has been elaborated and supplied with the survey. The questions are:

1. Methodologies are composed of tools that are oriented to investigate, explain and argue the objects of study. Does the methodology presented comply with the aforementioned?

2. Do you consider that the order of the phases of the methodology is correct?

3. Do you consider that the order of the stages within the problem delimitation phase is correct?

4. Do you consider that the order of the stages within the execution phase is correct?

5. Do you consider that the order of the stages within the construction and evaluation phase are correct?
6. Do you consider that the tools within the problem delimitation stage are adequate for the proposed methodology?
7. Do you consider that the tools within the execution stage are adequate for the proposed methodology?
8. Do you consider that the tools within the construction and evaluation stage are adequate for the proposed methodology?
9. Do you consider that the methodology is useful for the motorization change processes?
10. Do you consider that the flows within the problem delimitation phase are correct?
11. Do you consider that the flows within the execution phase of the problem are correct?
12. Do you consider that the flows within the construction and evaluation phase of the problem are correct?
13. Would you make any modification in the phases of the methodology?
14. Would you make any modification in the stages of the methodology?
15. Would you make any modification in the tools of the methodology?
16. Does the contact matrix facilitate the identification of key parts or interactions?
17. Would you use this methodology for a motorization change project?
18. Would you use this methodology for a project other than a motorization change?
19. Do you consider that this methodology could reduce the execution time of a project?
20. Do you consider that after following the methodology the objective of a motorization change can be achieved?
21. Does the proposed methodology allow to give order and follow-up to a project from the researcher's point of view?

For the survey of the T3 team, due to suggestions received for the final evaluation with this team, the question 20 has been removed since it was related to a previous question. In addition, the evaluation scale was modified to a Likert scale, in order to offer a graduation of the evaluators' opinion, also allowing a simpler way to perform the relevant analyses.

5.2 Analysis of results

5.2.1 Team 1 - Team directly related to the case study

The T1 evaluators consider that the methodology complies with the characteristics that generally constitute a methodology, since it directs the research towards a specific product and traces the route to take with respect to it, evaluating each of the stages, and giving clarity as to why they are necessary in the development.

The methodology integrates different tools for product design, focusing them on the redesign of mechanical systems and complementing them with the existing tools for the design stages. These tools allow to deepen the understanding of the problem in its delimitation phase, to justify the design decisions and identify the constraints in its execution phase, and to argue, from an engineering point of view, whether the solution is good or not, before the construction and evaluation phase.

The direct feedback on the tools is that they allow to evaluate the conditions from several points of view, taking into account several parameters, improving the possibilities for decision making. The evaluators would not make any modifications to them.

The proposed order allows to follow a logical sequence of steps, giving the option to iterate on several solutions, also facilitates the search for different alternative solutions to the problem, followed by the execution and feasibility of the same, and finally the construction. These stages include everything necessary for a clear selection process, knowing the segment to intervene.

This proposal makes it easier to define the user and the needs he/she may have, as several solution alternatives must be formulated, then choose the most suitable one, and, finally, evaluate if it is technically feasible.

The generation of prototypes after analyzing the possible solutions allows a dimensional and functional approach for the final testing of the product.

About the contact matrix, it allows to visualize graphically the degree and level of contribution of a part to others, set of these, subsystems and to the general system. It is simple and allows the prioritization of the parts.

The only thing that most do not agree with is the way to feedback the processes of stage 8 of phase 3, which is the final phase. They argue that the last phase is not clear and there is a lack of feedback that allows iteration in the generation of prototypes of the results found in the previous stages.

In general, the methodology seems adequate and agile for this type of projects. It can be used for any mechanical systems redesign project, it is concise for the approach and execution of a project. Finally, most of the evaluators agree that the objective of motorization change can be achieved by applying it.

5.2.2 Team 2 - Team no related to the case study

The evaluators consider that the exposed methodology provides a sequence of steps or systematic stages where, for each stage, a tool is being proposed that yields results allowing to advance or to go to the next step, achieving to conclude and delimit a research design problem.

The evaluators believe that the order within the phases and stages are correct because the way in which they were established is allowing to define what should be the physical properties that a product should have from the voice of the customer, and the study of a specific segment, as well as to determine the final engineering characteristics that will be required, that is, the needs and requirements of the users, it is attractive to go from the general to the particular of a project.

The general conclusion of the phases, stages and tools is that they are in a logical order, although they suggest considering the feedbacks between the stages of phase 3, to better arrive at a complex or defined design proposal.

Regarding the modifications to be made to the methodology and its usefulness, the following items are concluded:

To explicitly include iterative flows in phase 3 step 8.

The relationship and contact matrix adds value to the other commonly used tools, specifically the contact matrix, is a useful way to identify the parts that are related to each other and allows to prioritize each of the components, thus realizing the critical nature of each one.

The methodology is useful for any design and redesign process, and the step-by-step approach leads to the accomplishment of the modification in the motorization of a two-wheeled vehicle, and allows the researcher to identify how to standardize and how to manufacture a product derived from something already existing.

The conclusions, in general, are that the methodology has characteristics of inquiry, explanation and argumentation, the order of the phases and stages is correct, no modifications would be made neither in the phases nor in the stages, only in the flow of stage 8 in the phase 3, the methodology is useful for research projects.

5.2.3 Team 3 - Team of experts in methodologies

This team of evaluators obtained an evaluation generally with positive percentages, higher than 80% in most of the questions.

They all agree that the methodology is composed of tools that guide to inquire, explain and argue, and, they also consider that, the order of the phases and stages are correct.

Within the stages, some specified and pre-established tools are used, which were also fully accepted by the evaluators. No comments were received in this regard.

Regarding the usefulness of the methodology, 100% agree that for a motorization change process, the methodology proposed is suitable to meet the objective.

The only suggested modification is a feedback in the adjustment and improvement stage, but this has already been implemented in the methodology, so, this comment is already solved. Otherwise, no modifications are suggested in the phases, stages, flows or tools proposed.

For the evaluation of the contact matrix, all the evaluators agree that it facilitates the identification and interaction of the key parts: the proposed model is clear and allows a conclusive order in the identification of the critical parts, with this tool the relationship between the mechanical systems is identified, it marks the roadmap to ensure the correct modification, which allows the execution to be precise and allows the identification and definition of the criteria and key elements for the process.

They conclude that by defining the critical parts and systems that may be most affected, reprocesses are avoided and project execution time is optimized.

In terms of time reduction, having a structured methodology with organized phases, such as the one proposed, optimizes the time and resources of any project.

It is an agile methodology and allows to easily identify the evaluation criteria, which reduces the operation verification time.

All the evaluators would use the methodology for a motorization change project, in addition to the fact that the general steps are useful for other projects. Finally, they also consider that the proposed methodology gives order and follow-up to a project from the researcher's point of view.

5.2.4 General results

These results helped to make decisions to make changes and modifications on the methodological proposal.

100% of the respondents agree that the methodology presented is composed of inquiry, explanation and argumentation tools, and that the proposed tools allow to know the problem in depth, justify design decisions and validate an engineering solution.

The proposed structure outlines a step-by-step approach to the development of a research project focused on the motorization change of two-wheeled vehicles.

100% of the evaluators would not make any modifications to the phases, stages or tools proposed in the methodology.

Most of the results were positive, the modifications suggested with the flow in phase 3 were considered and carried out, and one more feedback was added in phase 2, thus adding 2 feedbacks, one in the technical evaluation stage (phase 2), and one in the adjustment stage (phase 3).

The contact matrix, the evaluators consider that it facilitates the identification of the key elements, it is a simple way to visualize how much a part interacts with the rest of the system to which it belongs, and identifies the relationship between the mechanical systems, the proposed model is clear and conclusive in the identification of the key parts and interactions in the methodology.

The evaluators conclude that the methodology is useful for a two-wheeler motorization modification project, and also that the general steps are useful not only for motorization change projects, but for any design and redesign project.

Finally, the results show that after following the methodology, the objective of a motorization change can be successfully achieved.

All the graphs for each of the questions can be found in the Appendix C.

Chapter 6

Conclusions

Of the articles reviewed on configurations and topologies in hybrid motorcycles, there are 15 articles, 12 are in parallel and 3 in series, concluding that 80% of the researches use the parallel topology due to advantages such as: weight, space, diversity in driving conditions, cost, among others. This is independent of mechanical or automatic transmission.

The bibliometric analysis shows that the greatest developments and research carried out for hybrid motorcycles have been done in the countries that lead the world market sales of this vehicle fleet, such as Taiwan with 17%, the United States and Italy with 14% each. It is also observed that most of them are in Scooter type motorcycles 68.7%, since having a CVT or automatic transmission facilitates the hybridization and control process.

It is concluded that the challenges found in the reviewed prototypes are:

- Space limitation.
- The additional weight to be supported by the motorcycle
- The modification of the aesthetic and physical part
- The constant modification of the center of mass that affects the aerodynamics of a motorcycle.
- The design of the electrical energy storage system

All the articles had more emphasis on a single challenge, i.e. dimensions or other batteries or controller or mechanics. There is not a single article that achieves a solution that meets all categories of the challenges.

25% of the main challenge was dimensional and related to the Electric Motor located at the rear, 31.2% related to the stability and aerodynamics challenge and related to the location of the Electric Motor at the front wheel, and, 44% related to dimensional challenges, coupling, modification of the center of gravity and related to the location of the Electric Motor in a central position or directly connected to the ICE.

In the developments or prototypes made in Street type motorcycles, it was evidenced that in the considerations and mechanical characteristics of the designs found are specific to the reference motorcycle to be modified, that is, there are 0% of standardized prototypes, in addition it is not clear neither the parts nor the mechanical adaptation processes that are performed, none is replicable in another, Furthermore, in the analysis of the state of the art of the methodologies, there is none that unifies the processes of design, redesign and standardization and they do not focus on the mechanical systems or the interaction of variables between them, so, after filtering the other methodologies, the phases, stages, tools and order for the proposal proposed in this work were obtained.

Considering the proposed case study, by applying the segment identification at the beginning of the methodology, it is possible to know the percentage of the market to be addressed, in the case study. By choosing the references of the four motorcycles and the Street segment, it was identified that 70% of the Colombian motorcycle market would be addressed.

With the 4 parts found in the contact matrix as critical, that is, with only 12% of the list of parts (described in the contact matrix) that make up the two-wheeled vehicle was sufficient to perform the experimental test assemblies, without the need to have the entire two-wheeled vehicle to verify the operation of the designed system.

With the application of the methodology, the standardization of the modification of 3 of the 4 references selected for the change of motorization in the case study was achieved, that is, 75% success rate.

The qualitative evaluation of the methodology showed that in all the questions asked, the average response rate was over 80% in a positive manner, that is to say, it was approved by the evaluators in all aspects, such as: order, flows, tools, logic, etc.

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Appendix A

Pre-established templates in the methodology

A.1 Contact matrix

CONTACT MATRIX BETWEEN SYSTEMS

Two-wheeled motor vehicle systems		Front braking system				Rear braking system				Front traction system				Rear Traction System				Dragging system					Front damping system		Rear damping system		Main support system	Front support system		Rear support system			Propulsion system		Evaluation
		Brake bell	Drum / Disc	Direct Drive	Indirect Drive	Brake bell	Drum / Disc	Direct Drive	Indirect Drive	Pneumatic	Rhine	Spokes / Blades	Supporting block	Pneumatic	Rhine	Spokes / Blades	Pneumatic	Sprocket	Screws	Chain	Output sprocket	Tensioner	Shock absorber spring	Piston	Shock absorber spring	Piston	Chassis	Swing arm	Handlebar	Swing arm	Through shaft	Chassis support shaft	Combustion engine	Gearbox	
Front braking system	Brake bell																																		0
	Drum / Disc																																		0
	Direct Drive																																		0
	Indirect Drive																																		0
Rear braking system	Brake bell																																		0
	Drum / Disc																																		0
	Direct Drive																																		0
	Indirect Drive																																		0
Front traction system	Pneumatic																																		0
	Rhine																																		0
	Spokes / Blades																																		0
	Supporting block																																		0
Rear Traction System	Pneumatic																																		0
	Rhine																																		0
	Spokes / Blades																																		0
	Pneumatic																																		0
Dragging system	Sprocket																																		0
	Screws																																		0
	Chain																																		0
	Output sprocket																																		0
	Tensioner																																		0
Front damping system	Shock absorber spring																																		0
	Piston																																		0
Rear damping system	Shock absorber spring																																		0
	Piston																																		0
Main support system	Chassis																																		0
Front support system	Swing arm																																		0
	Handlebar																																		0
Rear support system	Swing arm																																		0
	Through shaft																																		0
	Chassis support shaft																																		0
Propulsion system	Combustion engine																																		0
	Gearbox																																		0

Figure A.1: Contact Matrix template

CONTACT MATRIX BETWEEN SYSTEMS

Two-wheeled motor vehicle systems		Front braking system				Rear braking system				Front traction system				Rear Traction System				Dragging system					Front damping system		Rear damping system		Main support system	Front support system		Rear support system			Propulsion system		Evaluation
		Brake bell	Drum / Disc	Direct Drive	Indirect Drive	Brake bell	Drum / Disc	Direct Drive	Indirect Drive	Pneumatic	Rhine	Spokes / Blades	Supporting block	Pneumatic	Rhine	Spokes / Blades	Pneumatic	Sprocket	Screws	Chain	Output sprocket	Tensioner	Shock absorber spring	Piston	Shock absorber spring	Piston	Chassis	Swing arm	Handlebar	Swing arm	Through shaft	Chassis support shaft	Combustion engine	Gearbox	
Front braking system	Brake bell		1										1																						2
	Drum / Disc	1		1																															2
	Direct Drive		1		1																														2
	Indirect Drive			1																									1						2
Rear braking system	Brake bell						1										1														1				3
	Drum / Disc					1		1																											2
	Direct Drive						1		1																										2
	Indirect Drive							1																											1
Front traction system	Pneumatic										1																								1
	Rhine									1		1																							2
	Spokes / Blades										1		1																						2
	Supporting block	1										1																							2
Rear Traction System	Pneumatic														1																				1
	Rhine													1		1																			2
	Spokes / Blades														1		1																		2
	Pneumatic	1														1		1	1												1				5
Dragging system	Sprocket																1		1	1															3
	Screws																1	1																	2
	Chain																	1			1														2
	Output sprocket																			1													1		2
	Tensioner																													1	1				2
Front damping system	Shock absorber spring																							1											1
	Piston																						1					1	1						3
Rear damping system	Shock absorber spring																									1									1
	Piston																								1		1			1					3
Main support system	Chassis																									1		1	1	1		1	1		6
Front support system	Swing arm																							1			1		1						3
	Handlebar				1																			1			1	1							4
Rear support system	Swing arm																					1				1	1				1	1			5
	Through shaft					1											1					1								1					4
	Chassis support shaft																										1			1					2
Propulsion system	Combustion engine																				1						1							1	3
	Gearbox																																1		1

Figure A.2: Contact Matrix

A.2 Relationship matrix template

Requirements Category	Category Rating	User Requirements	Specifications	Limit	Priority	Individual Scoring	Hierarchy
Cost Objective	5	The value of the kit should not exceed half of the commercial value of the selected motorcycles.	Total value of the kit.	X < $ 2'450.000 COP	8	40	12
Performance	5	The kit should make the motorcycle more efficient.	Equivalent energy efficiency.	128 <x<175 (Km/Gal)	9	45	5
			Increase in total mass.	14.2<x<19.2 (kg)	10	50	1
		The kit must resist water, dust and temperature..	IP protection degree.	x=IP 55	10	50	2
		Improve the acceleration of the motorcycle.	Incremento en la masa total.	14.2<x<19.2(kg)	10	50	3
			Maximum torque	8.05<x<10.8 (N.m)	9	45	6
		Maintains motorcycle speed.	Maximum power	8.09<x<12.82 (Hp)	9	45	7
		Maintains the consumption of the motorcycle.	Equivalent energy efficiency.	128<x<175(Km/Gal)	6	30	13
		The kit must have a minimum power consumption.	Overall energy efficiency.	x=50% (Total energy)	5	25	15
Service Life	3	The kit must maintain the warranty and originality of the motorcycle.	Service life of electrical machines.	x>=20.000 (km)	7	21	27
			Service life of mechanical components.	x>=20.000 (km)	8	24	25
			Service life of main transmission and wear elements.	x>=5.000 (km)	5	15	29
			Service life of brake system wear elements.	x>=5.000 (km)	4	12	31
Manufacturing	4	Be minimally invasive with the motorcycle parts.	Modifications to the original motorcycle	x<10 (#)	7	28	18
		Must be standard for STREET type motorcycles. / The kit must be adjusted to the technical characteristics of at least 2 of the 4 motorcycles. / The kit must be available at a parts store.	Street motorcycle segment.	x>=2 (#)	8	32	16
		The kit should not require specialized tools for installation.	Specialized tools.	x<2(#)	4	16	28
		Easy to install and uninstall.	Time required to install the kit.	x<10 (h/man)	7	28	19
Environment	3	Not affect waste generation.	Reduction of hydrocarbons per km.	x>=20%	7	21	20
			Carbon monoxide reduction per km.	x>=20%	7	21	21
		Cannot be noisy.	Intensity.	x>86 (db)	9	27	17
Maintenance	3	Be maintainable. / It should not have a long maintenance time.	Time required to perform maintenance.	x<3 (h/man)	7	21	26
		The kit does not require specialized tools for maintenance. / Easy to clean and wash.	Specialized tools.	x<2 (#)	8	24	22
		Easy visual inspection for the kit.	Time required to make a visual inspection.	x<0.25 (h/man)	4	12	30
Dimensions and weights	5	The kit must maintain the load capacity of the motorcycle. / The kit must not alter the load or the passenger or the package.	Maximum weight allowed.	130<x<173 (kg)	8	40	9
		It does not increase the original dimensions of the motorcycle.	Maximum length allowed.	1900<x<2035 (mm)	8	40	10
			Maximum height allowed.	800<x<1080 (mm)	8	40	11
			Maximum width allowed.	714<x<770 (mm)	10	50	4
			Maximum permissible wheelbase.	1235<x<1310 (mm)	6	30	14
		It must be a compact kit.	Volume occupied on the motorcycle.	x<40 (L)	9	45	8
Comfort and safety	3	The kit must maintain the motorcycle's rideability.	Center of gravity.	x<=x motorcycle (#)	7	21	23
		It must be safe.	Safety factor.	x<=2 (#)	7	21	24

	Check list of specifications
1	Increase in total mass.
2	IP protection degree.
3	Incremento en la masa total.
4	Maximum width allowed.
5	Equivalent energy efficiency.
6	Maximum torque
7	Maximum power
8	Volume occupied on the motorcycle.
9	Maximum weight allowed.
10	Maximum length allowed.
11	Maximum height allowed.
12	Total value of the kit.
13	Equivalent energy efficiency.
14	Maximum permissible wheelbase.
15	Overall energy efficiency.
16	Street motorcycle segment.
17	Intensity.
18	Modifications to the original motorcycle
19	Time required to install the kit.
20	Reduction of hydrocarbons per km.
21	Carbon monoxide reduction per km.
22	Specialized tools.
23	Center of gravity.
24	Safety factor.
25	Service life of mechanical components.
26	Time required to perform maintenance.
27	Service life of electrical machines.
28	Specialized tools.
29	Service life of main transmission and wear elements.
30	Time required to make a visual inspection.
31	Service life of brake system wear elements.

Figure A.3: Relationship matrix case of study

Appendix B

Technical design drawings

In the figures B.1, B.2 and B.3, are shown the drawings with the dimensions and detailed geometries of the first designs of the traction and coupling system of the ICE and EM, where as explained above had 3 fundamental manufacturing parts which was the plate that covers the EM, the portasprocket and a plate where the sprocket of all motorcycle references is adapted, called universal plate; which is later eliminated after the stage of adjustments and improvements, this along with the change of one of the ball bearings, some modifications in the portasprocket as can be compared between figure B.3 and figure B.5 and a difference in the depth of the EM cover.

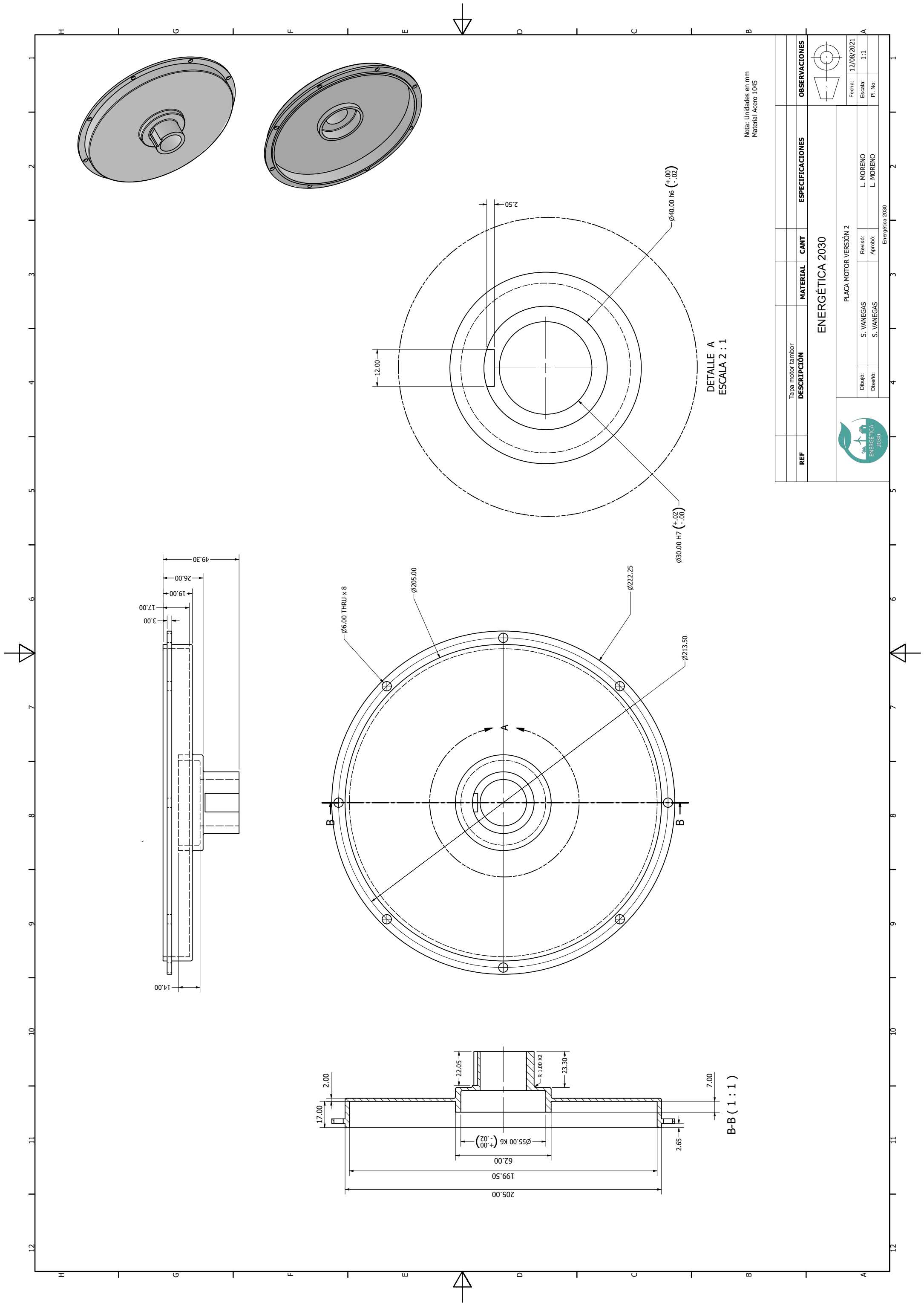

Figure B.1: Engine cover design 1

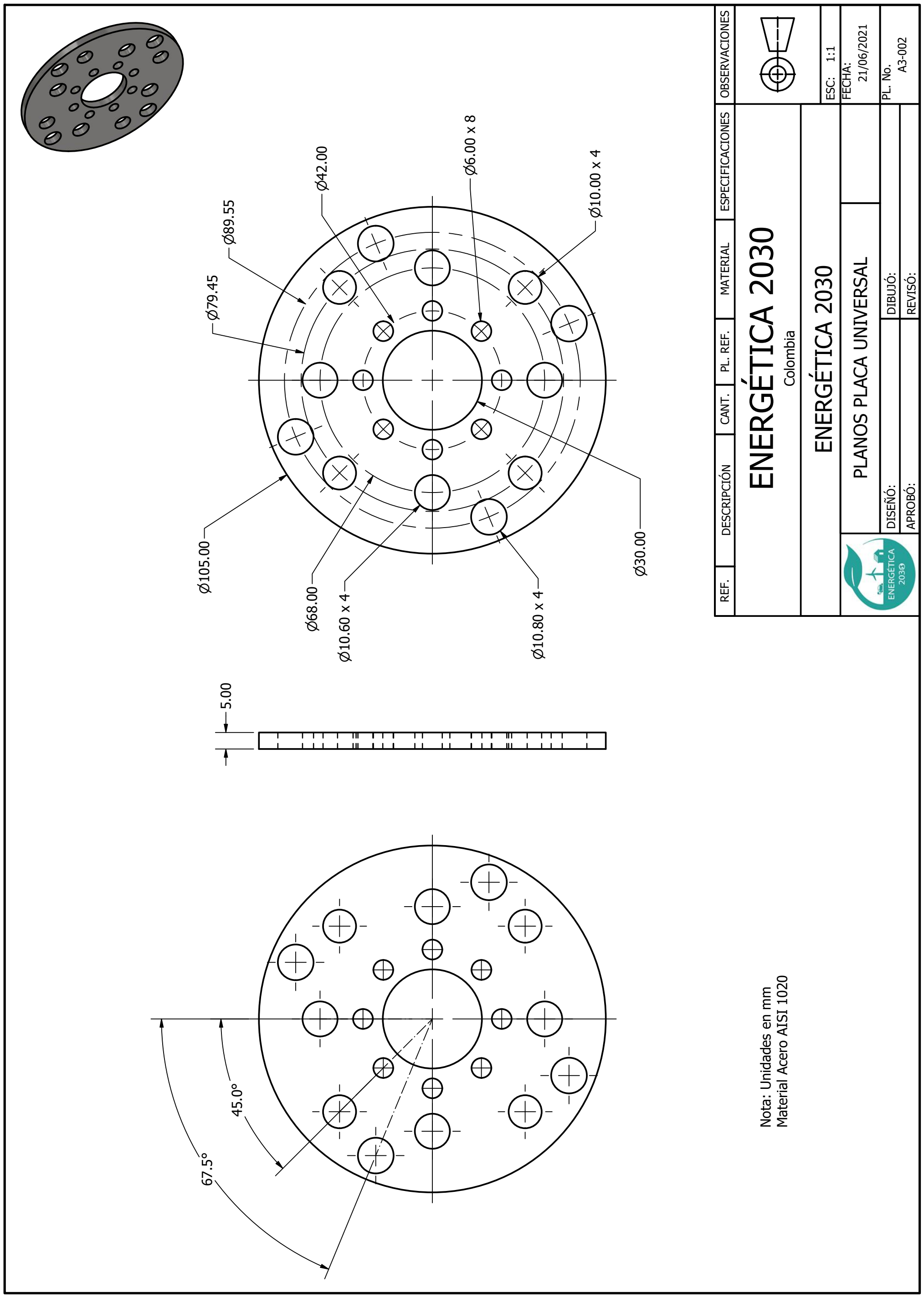

Figure B.2: Universal adapter plate

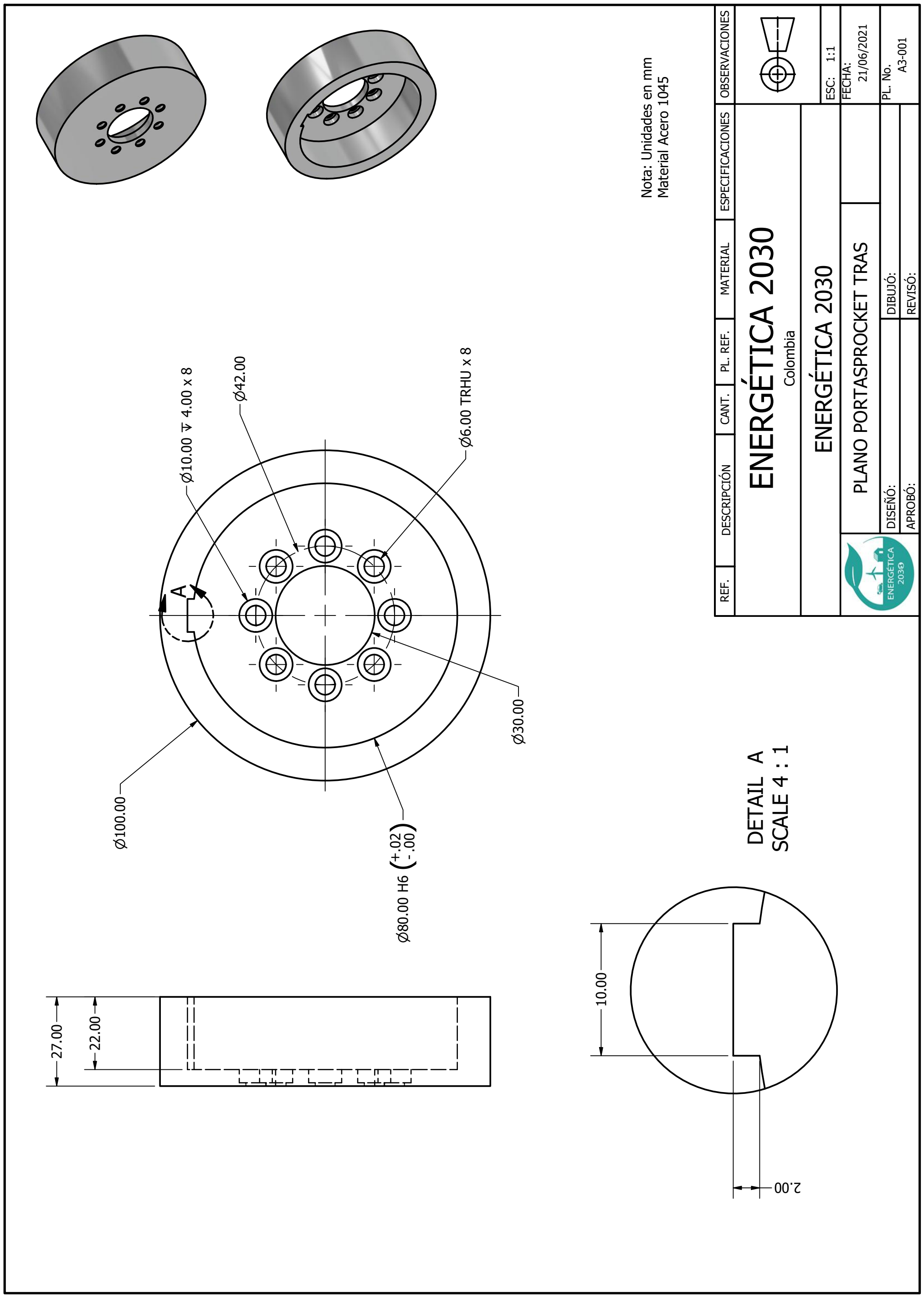

Figure B.3: Portasprocket design 1

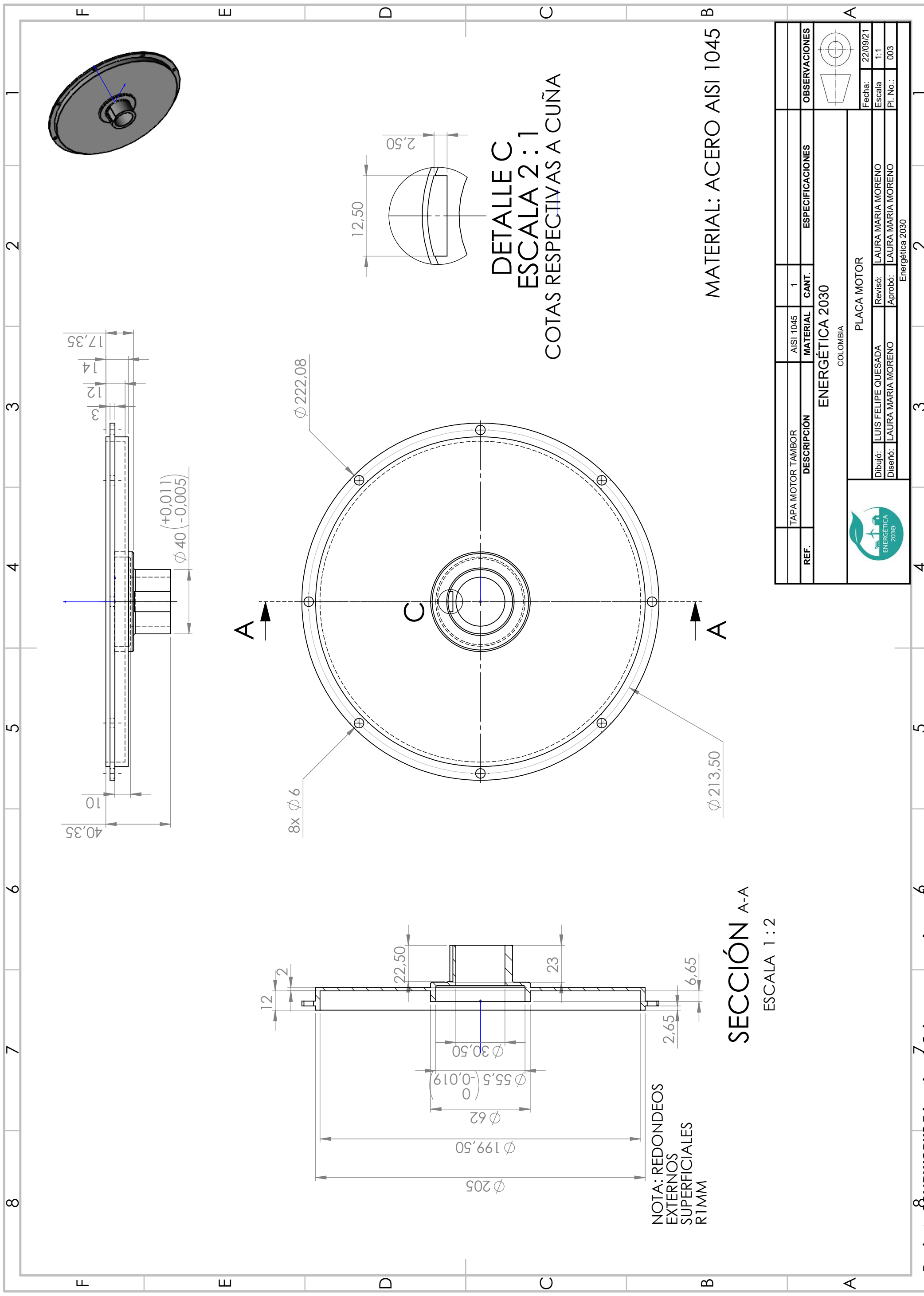

Figure B.4: Engine cover design 1

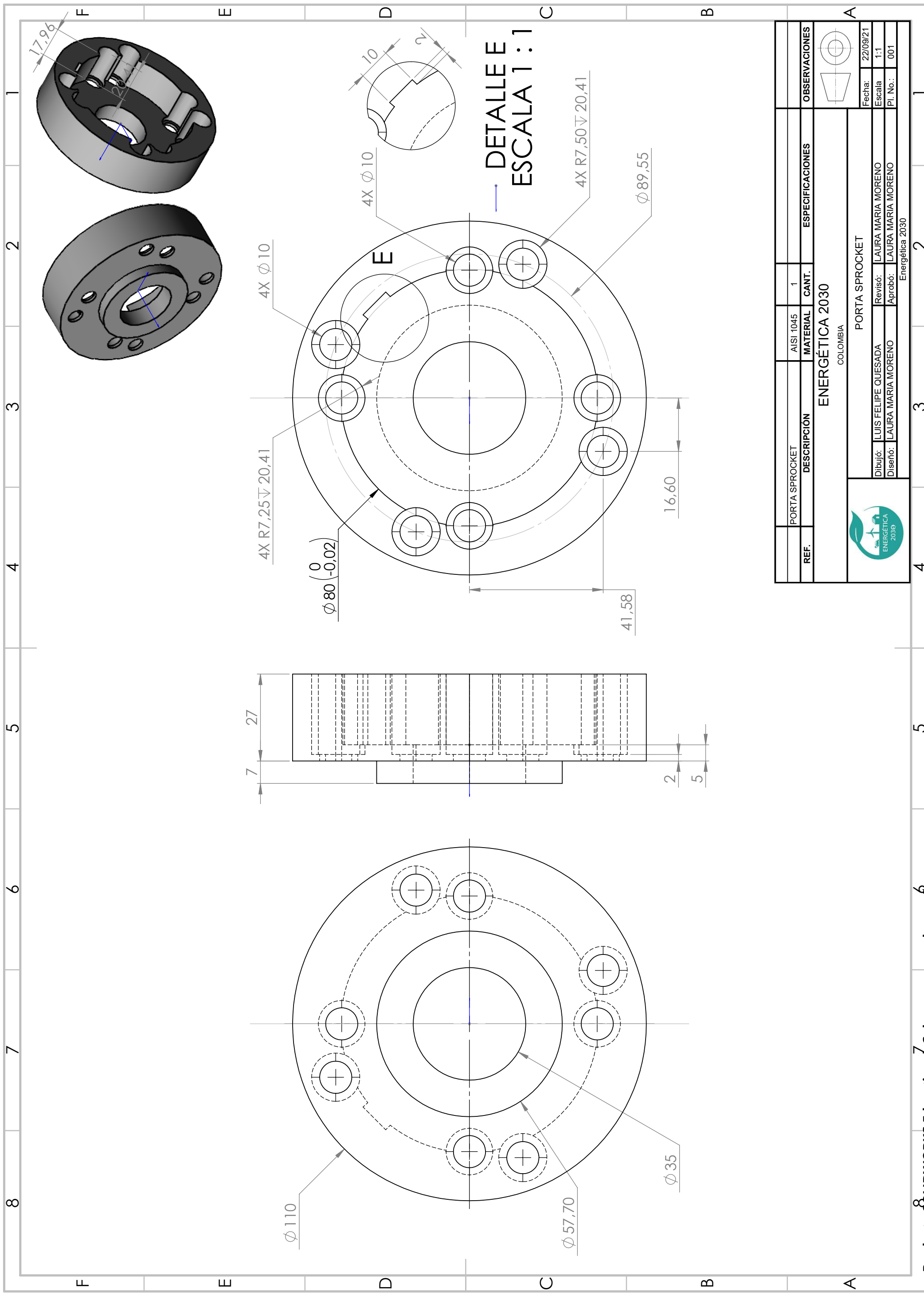

Figure B.5: Portasprocket design 2

Appendix C

Graphical results of the surveys

C.1 Results graphs - Team 1 (T1)

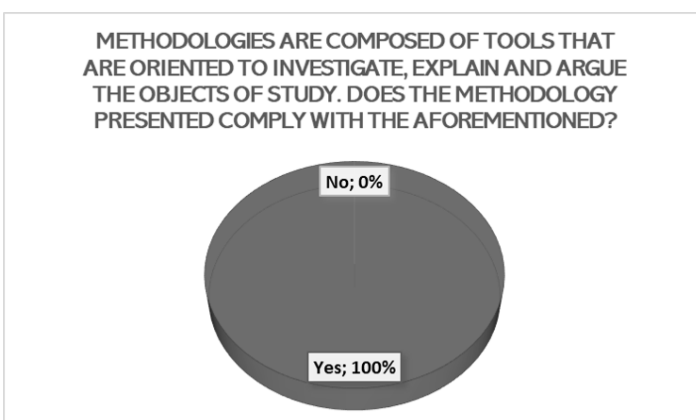

Figure C.1: Results of question 1- T1

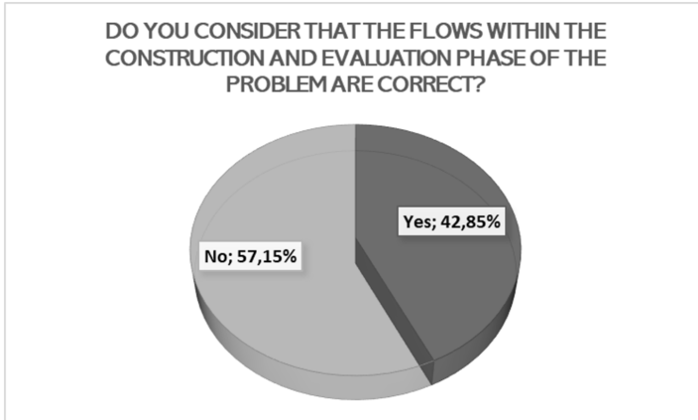

Figure C.2: Results of question 2- T1

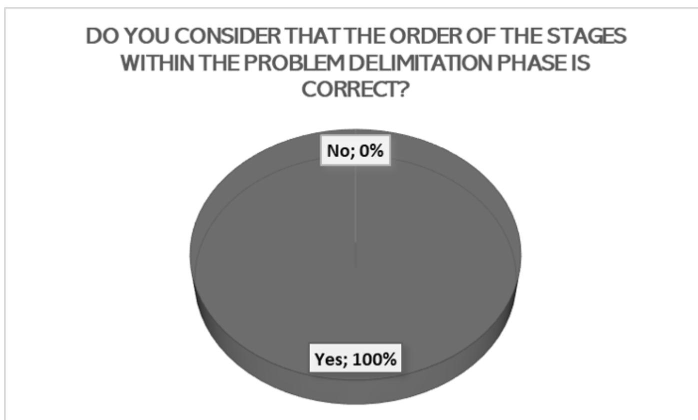

Figure C.3: Results of question 3- T1

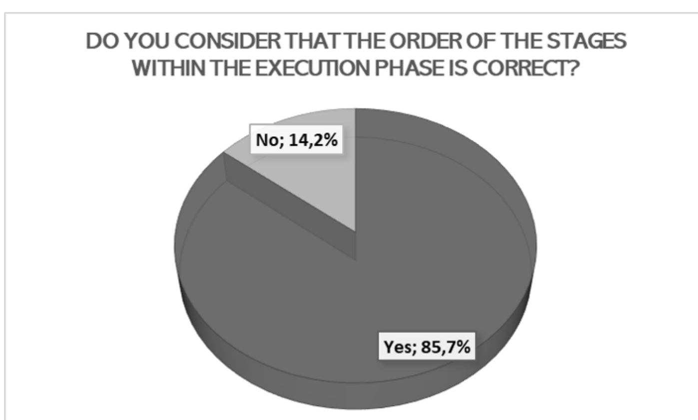

Figure C.4: Results of question 4- T1

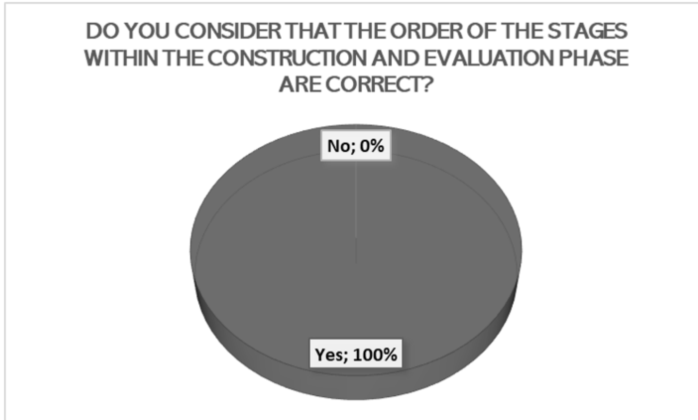

Figure C.5: Results of question 5- T1

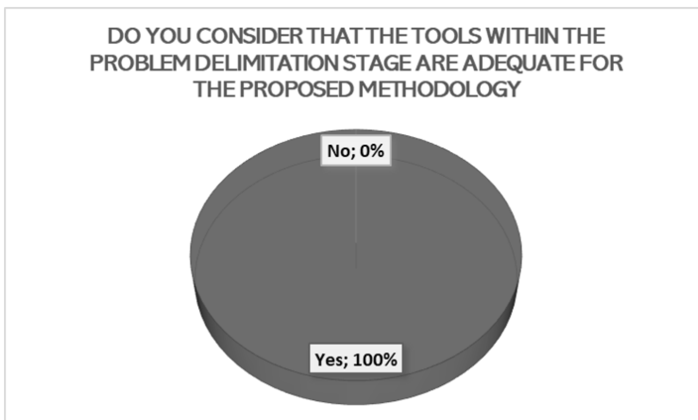

Figure C.6: Results of question 6- T1

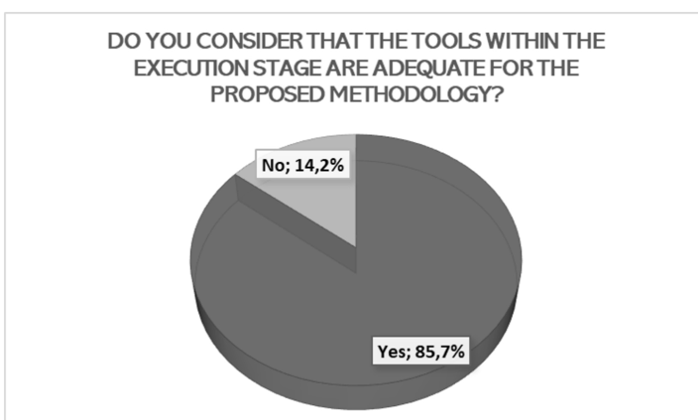

Figure C.7: Results of question 7- T1

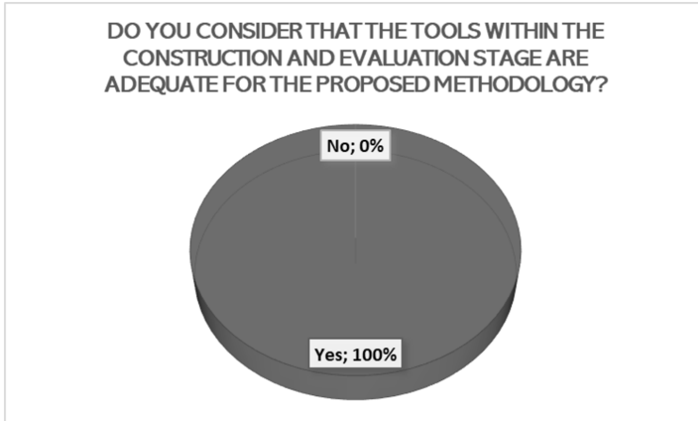

Figure C.8: Results of question 8- T1

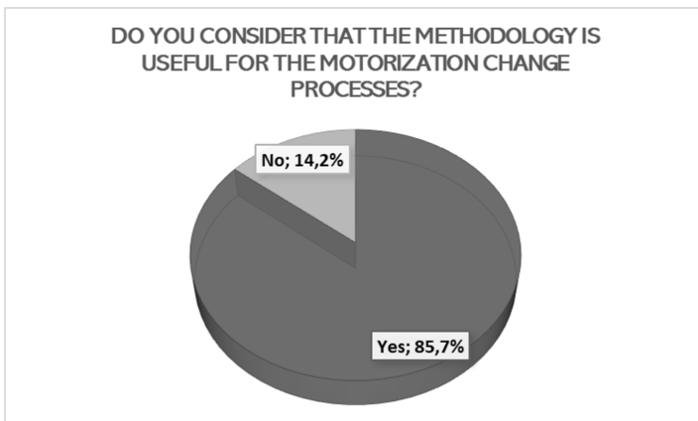

Figure C.9: Results of question 9 - T1

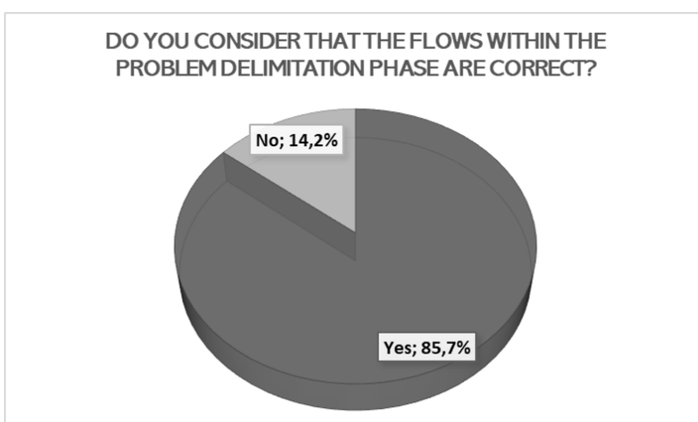

Figure C.10: Results of question 10- T1

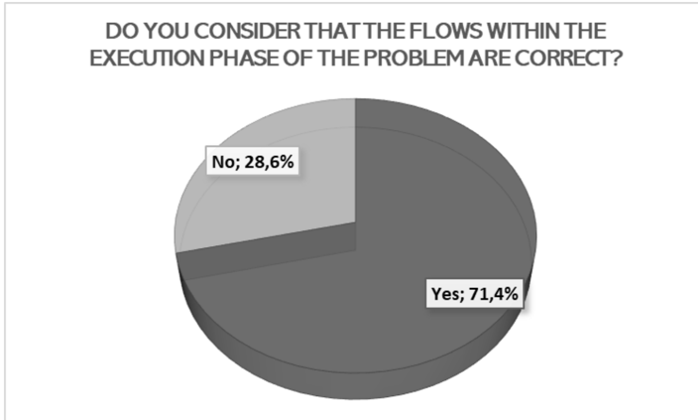

Figure C.11: Results of question 11- T1

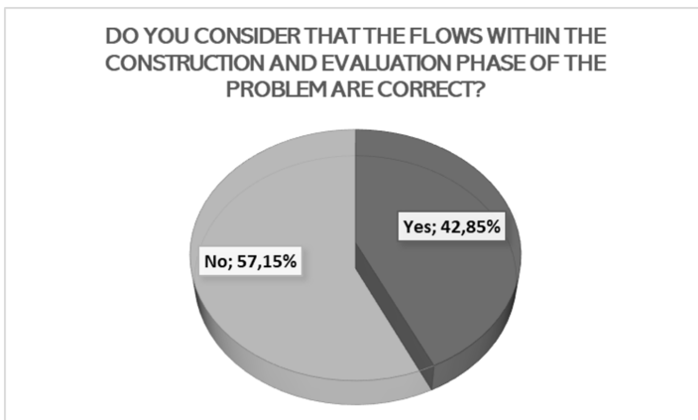

Figure C.12: Results of question 12- T1

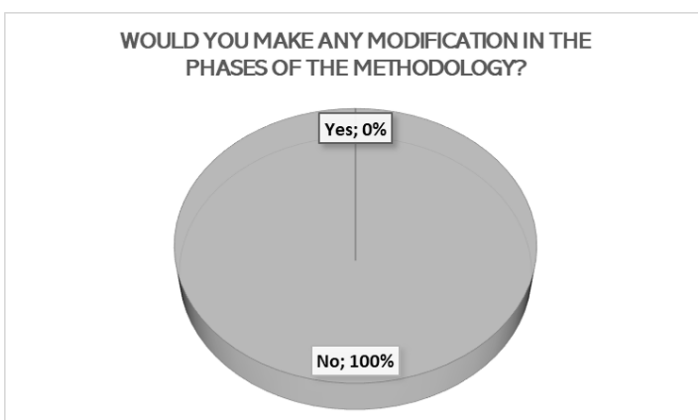

Figure C.13: Results of question 13- T1

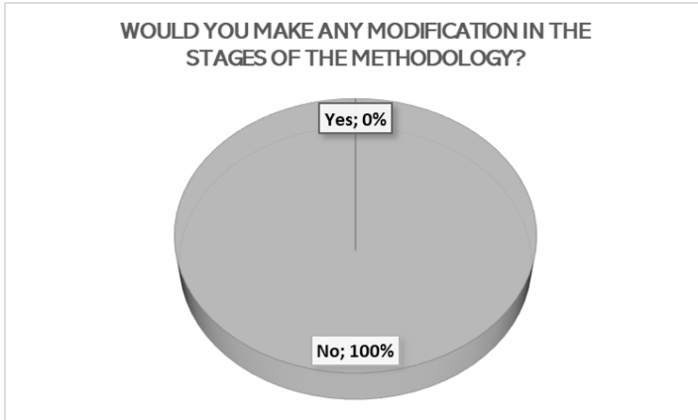

Figure C.14: Results of question 14- T1

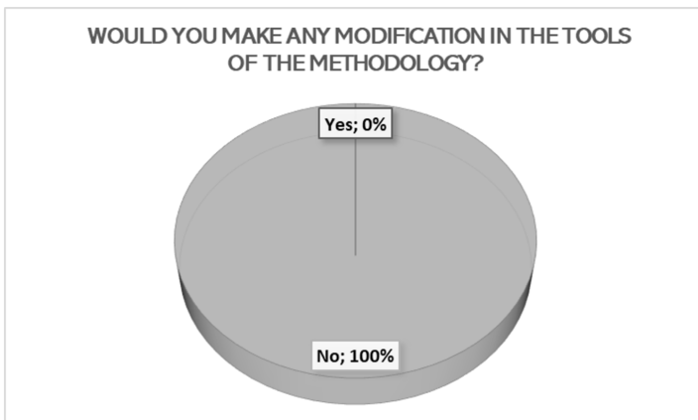

Figure C.15: Results of question 15- T1

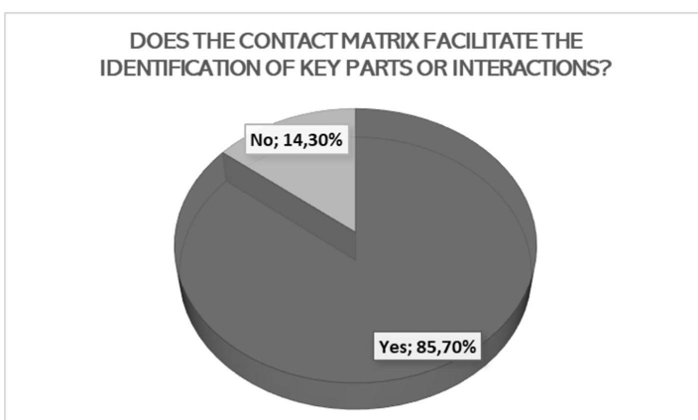

Figure C.16: Results of question 16- T1

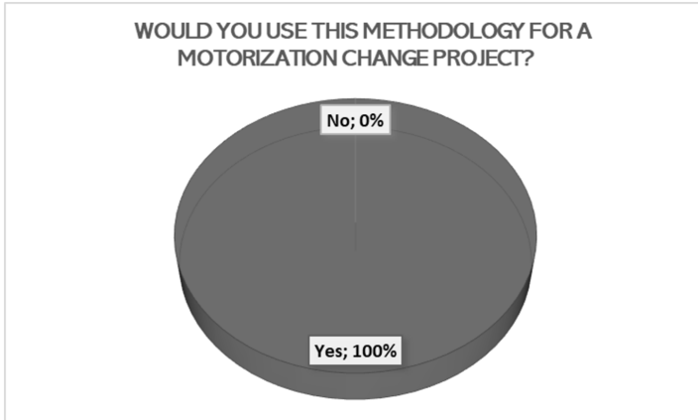

Figure C.17: Results of question 17- T1

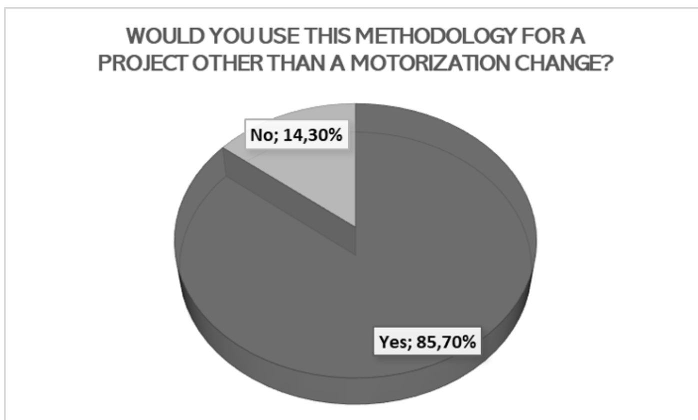

Figure C.18: Results of question 18- T1

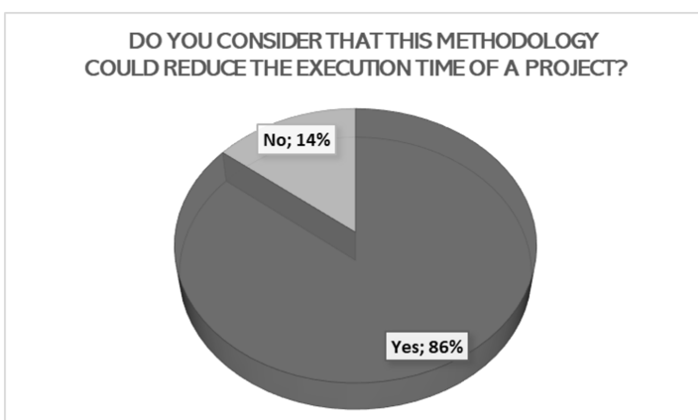

Figure C.19: Results of question 19- T1

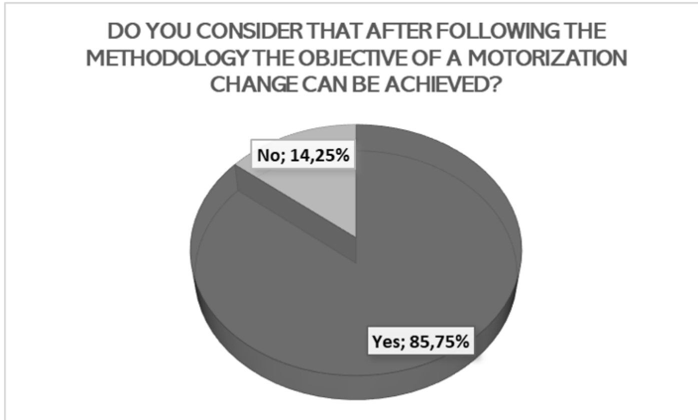

Figure C.20: Results of question 20- T1

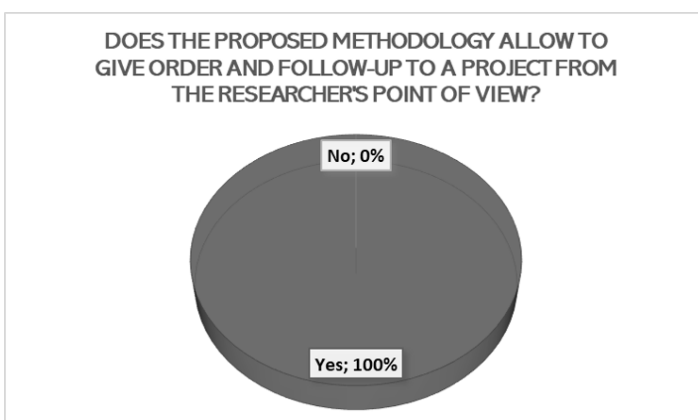

Figure C.21: Results of question 21- T1

C.2 Results graphs - Team 2 (T2)

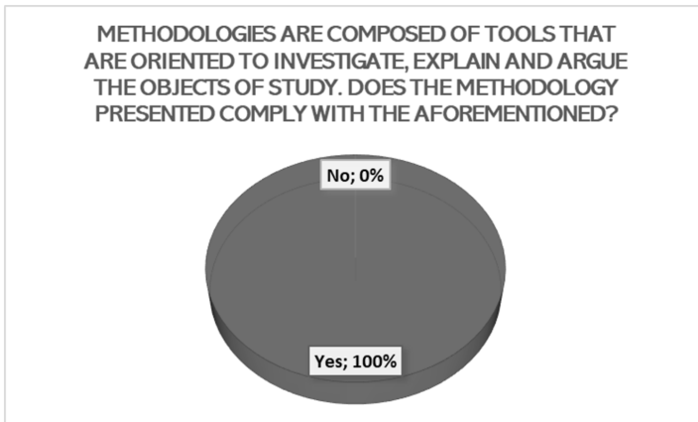

Figure C.22: Results of question 1- T2

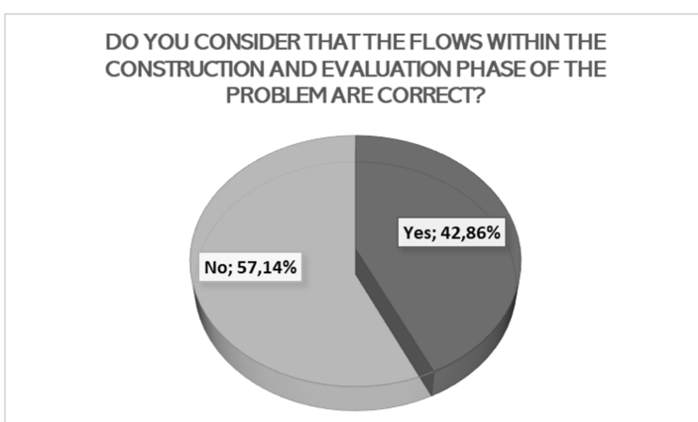

Figure C.23: Results of question 2- T2

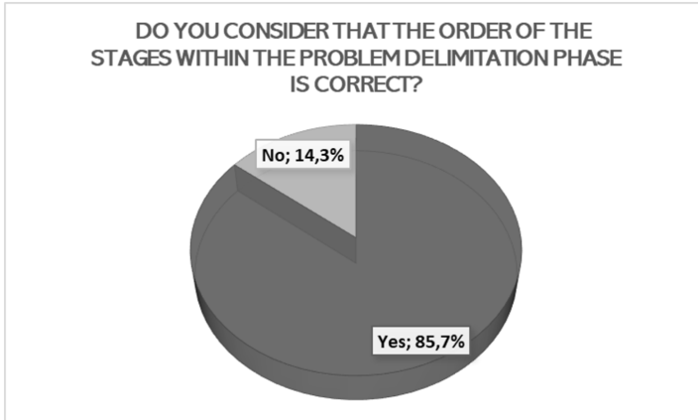

Figure C.24: Results of question 3- T2

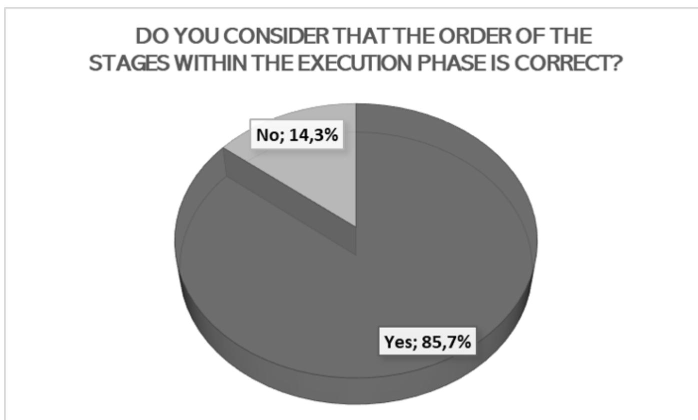

Figure C.25: Results of question 4- T2

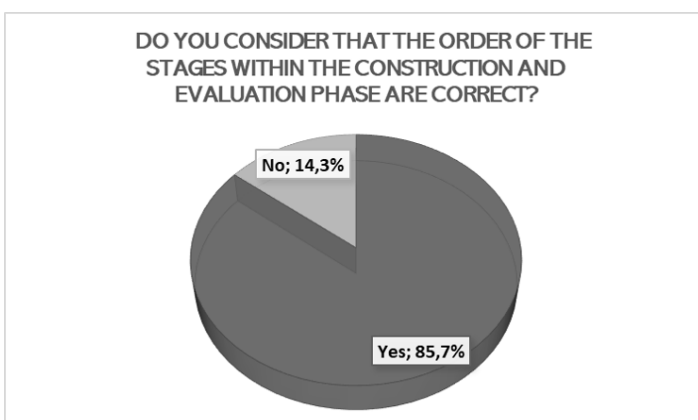

Figure C.26: Results of question 5- T2

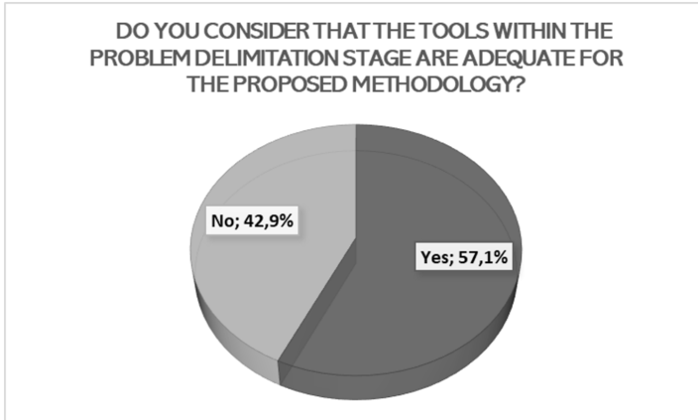

Figure C.27: Results of question 6- T2

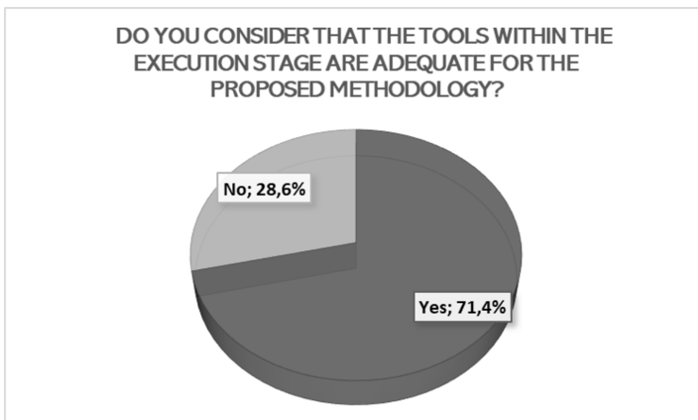

Figure C.28: Results of question 7- T2

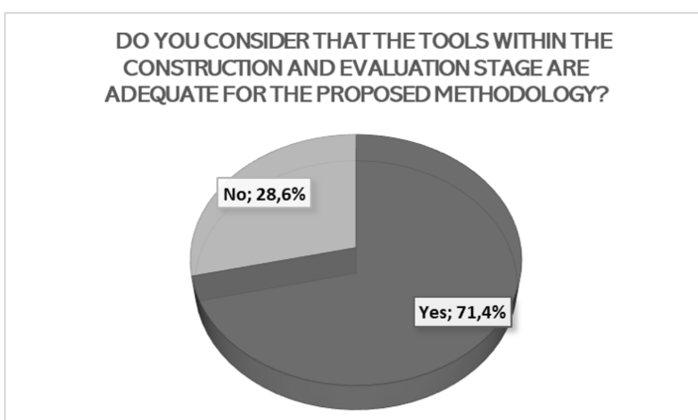

Figure C.29: Results of question 8- T2

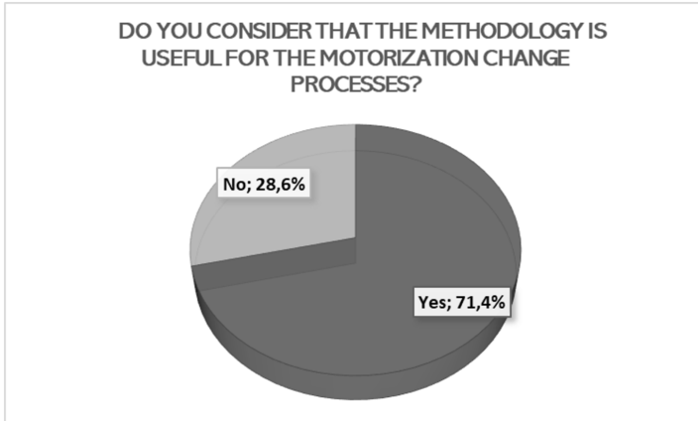

Figure C.30: Results of question 9 - T2

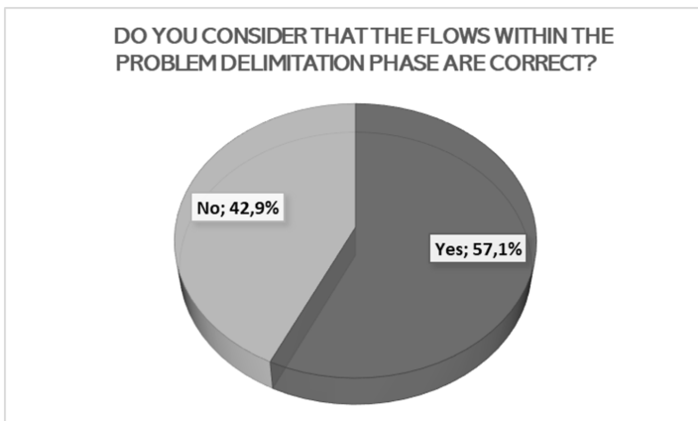

Figure C.31: Results of question 10- T2

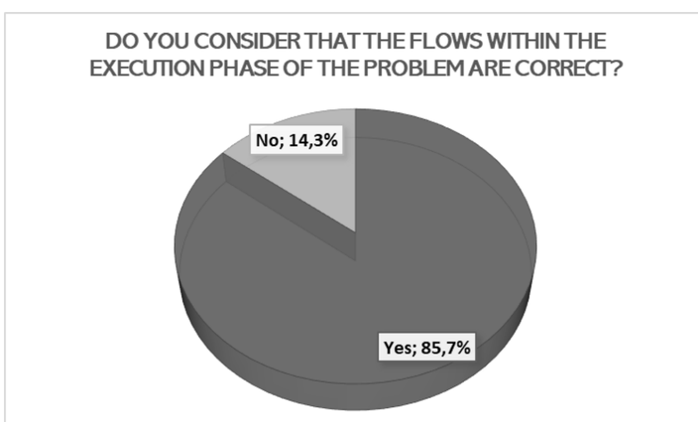

Figure C.32: Results of question 11- T2

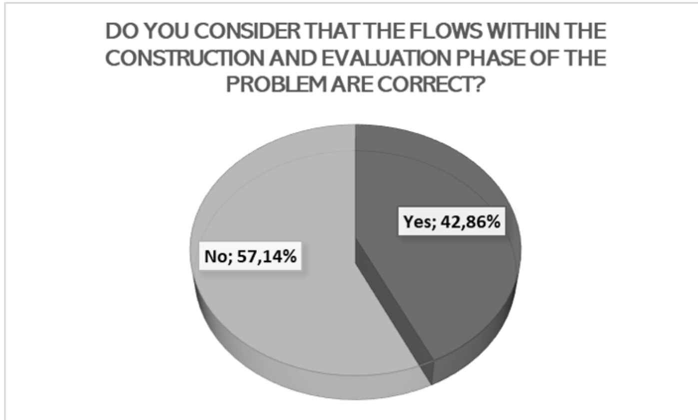

Figure C.33: Results of question 12- T2

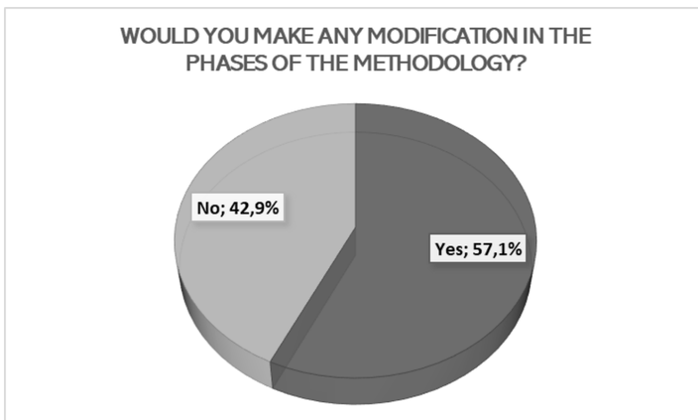

Figure C.34: Results of question 13- T2

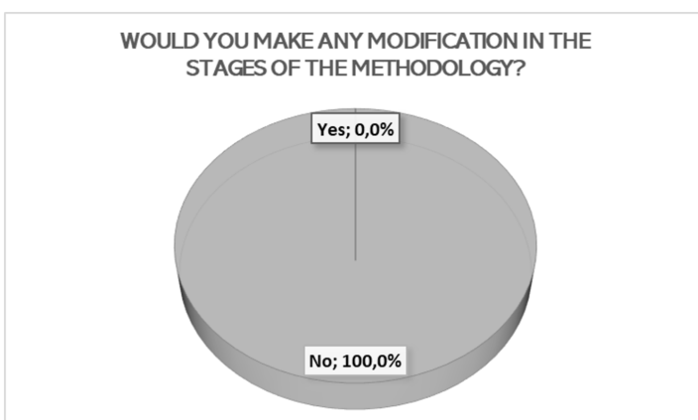

Figure C.35: Results of question 14- T2

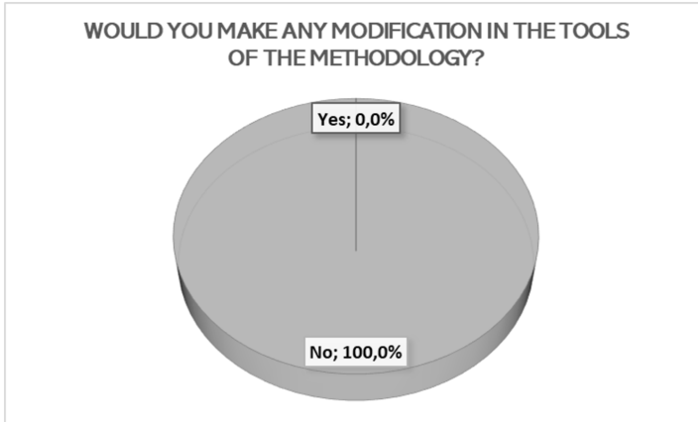

Figure C.36: Results of question 15- T2

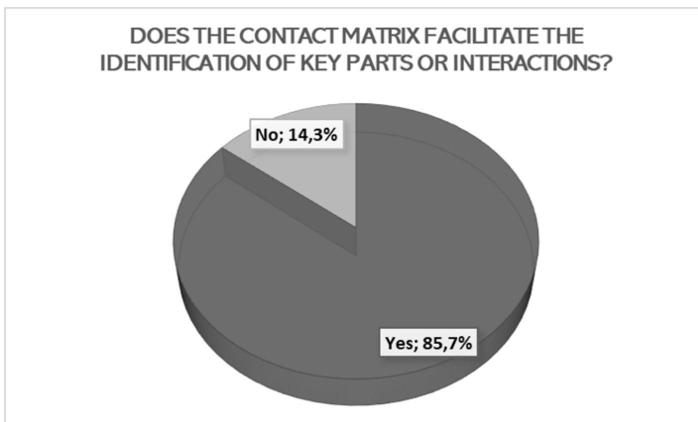

Figure C.37: Results of question 16- T2

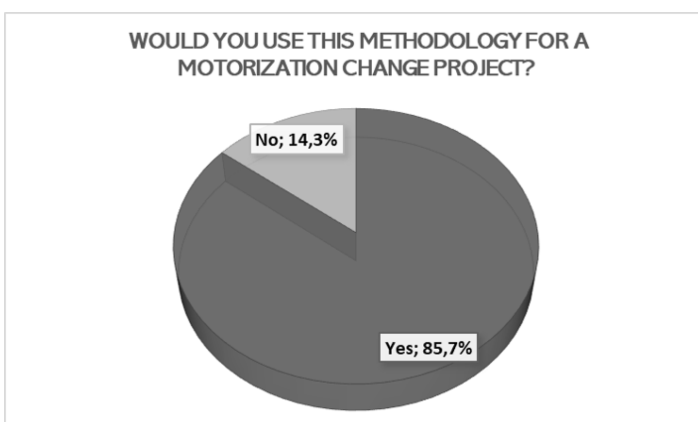

Figure C.38: Results of question 17- T2

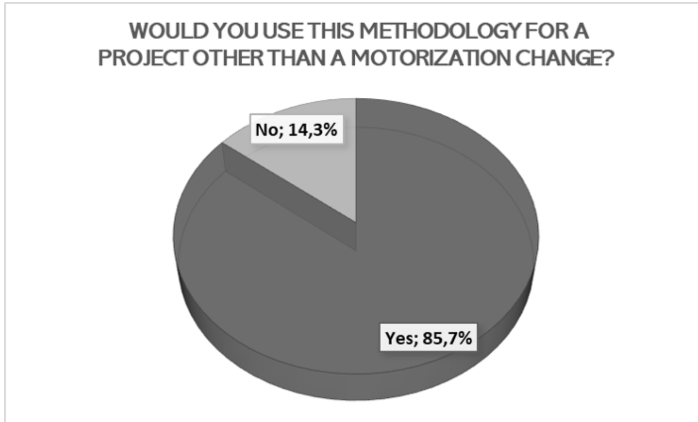

Figure C.39: Results of question 18- T2

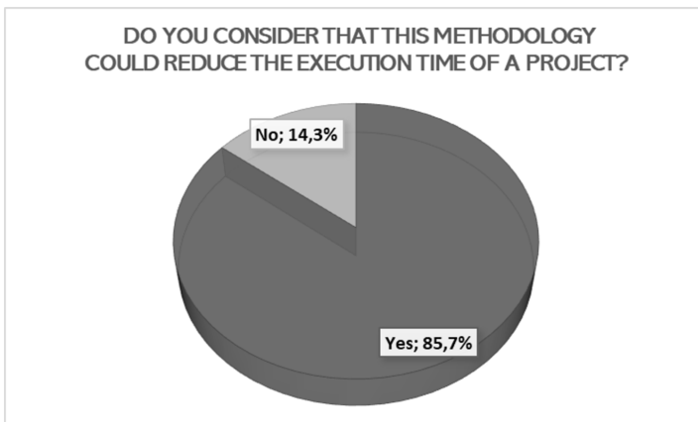

Figure C.40: Results of question 19- T2

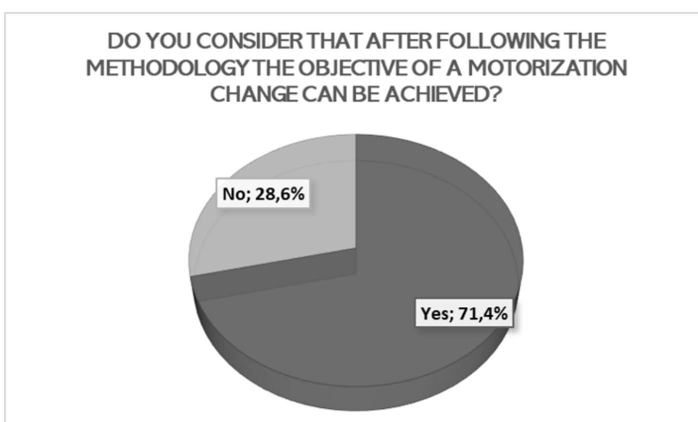

Figure C.41: Results of question 20- T2

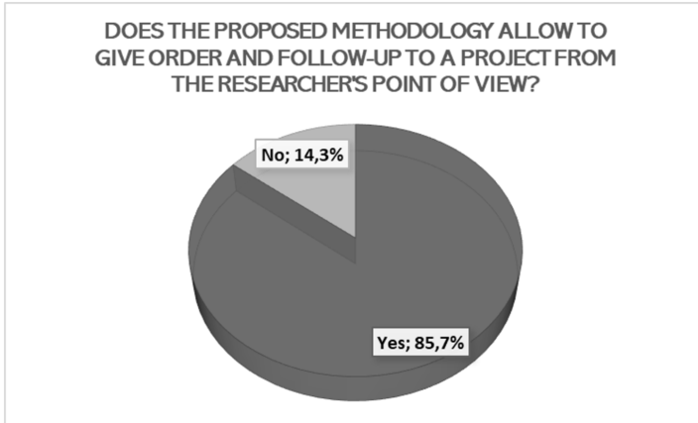

Figure C.42: Results of question 21- T2

C.3 Results graphs - Team 3 (T3)

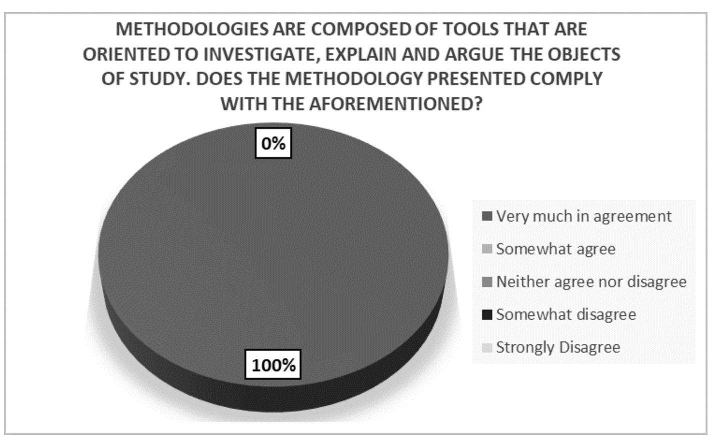

Figure C.43: Results of question 1- T3

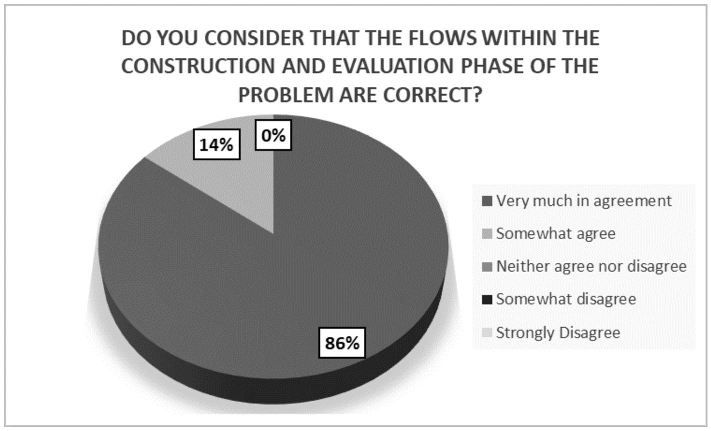

Figure C.44: Results of question 2- T3

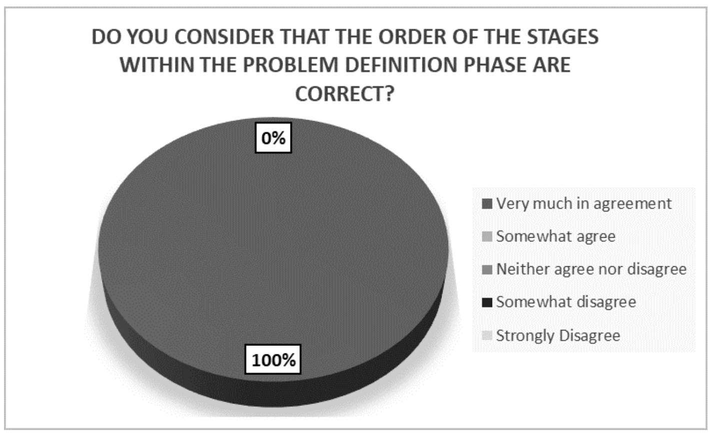

Figure C.45: Results of question 3- T3

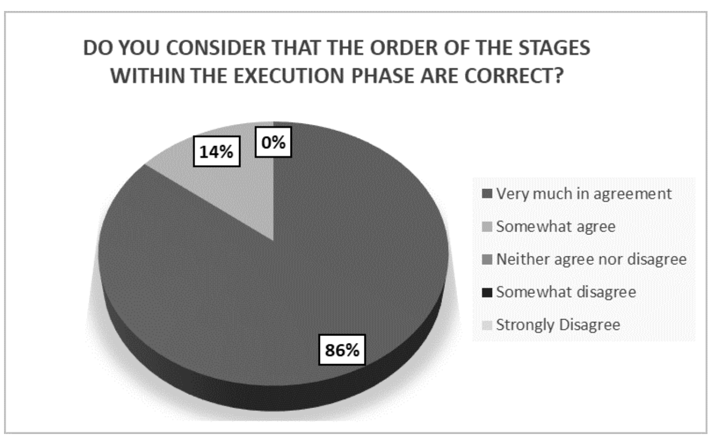

Figure C.46: Results of question 4- T3

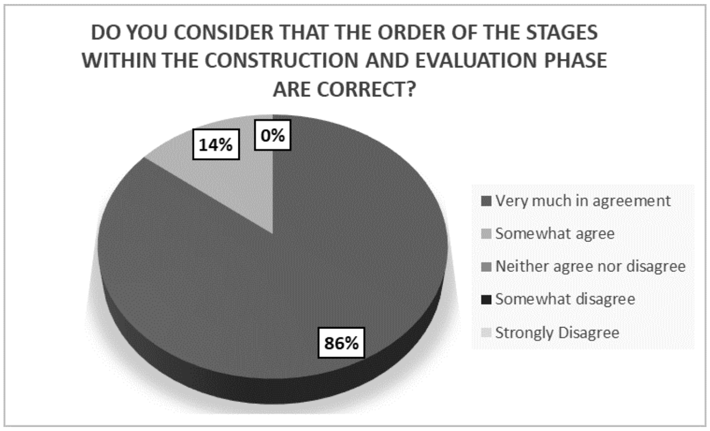

Figure C.47: Results of question 5- T3

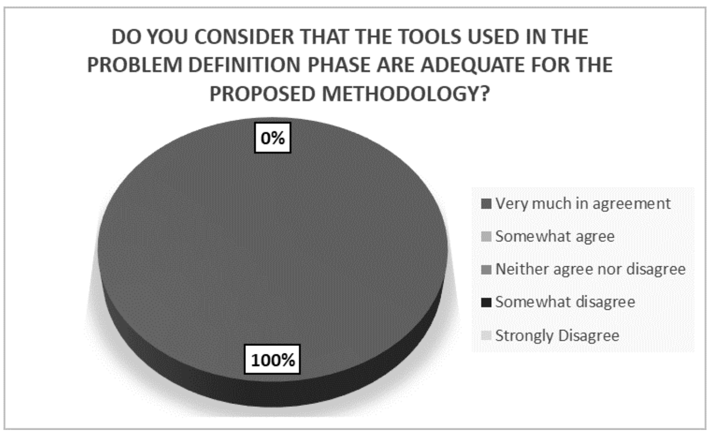

Figure C.48: Results of question 6- T3

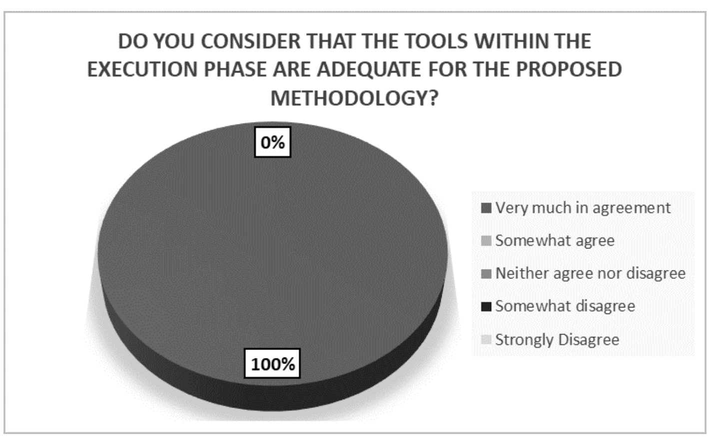

Figure C.49: Results of question 7- T3

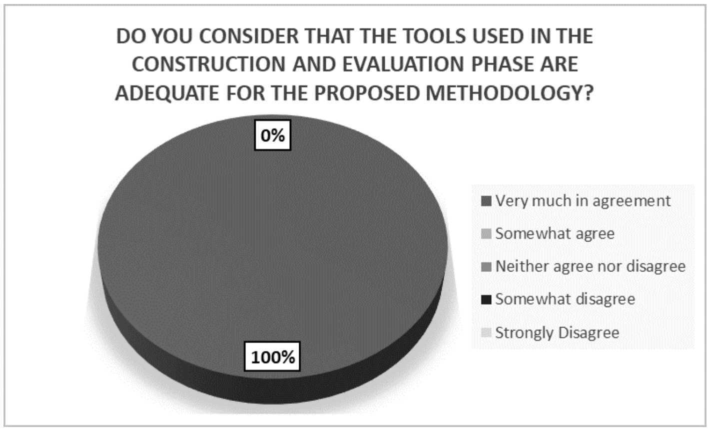

Figure C.50: Results of question 8- T3

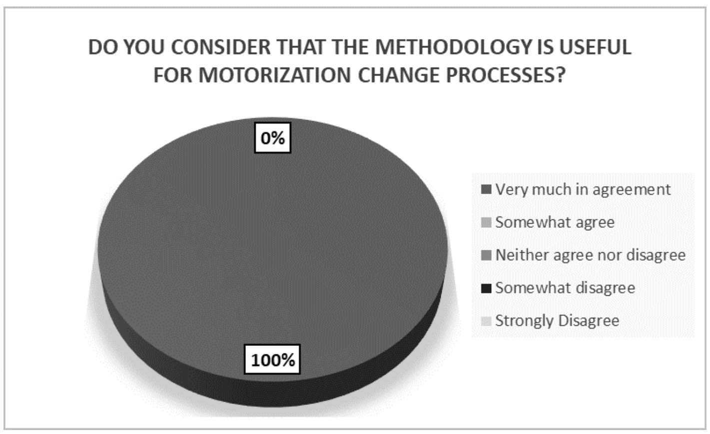

Figure C.51: Results of question 9 - T3

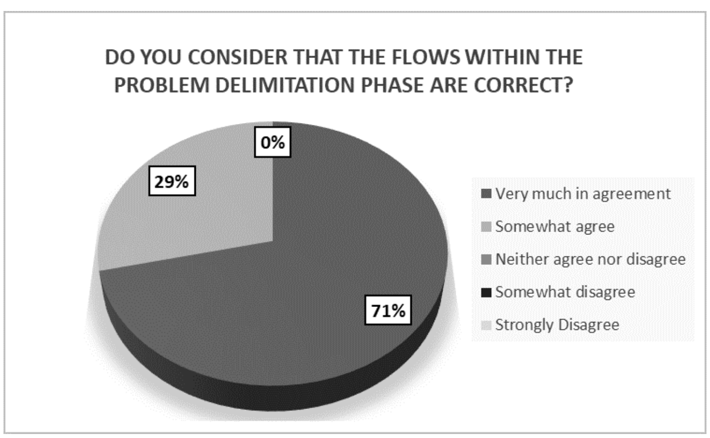

Figure C.52: Results of question 10- T3

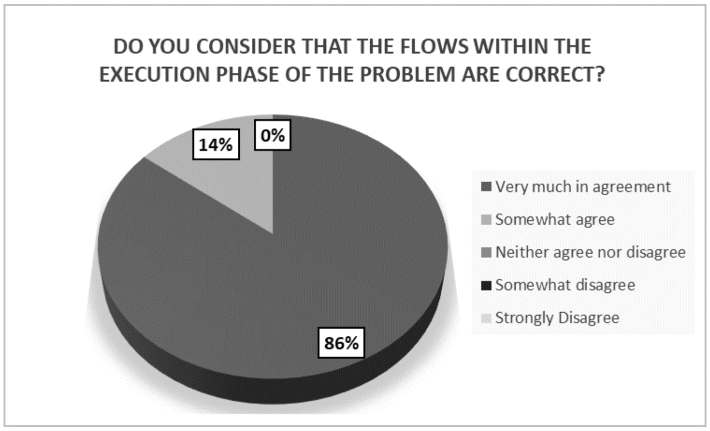

Figure C.53: Results of question 11- T3

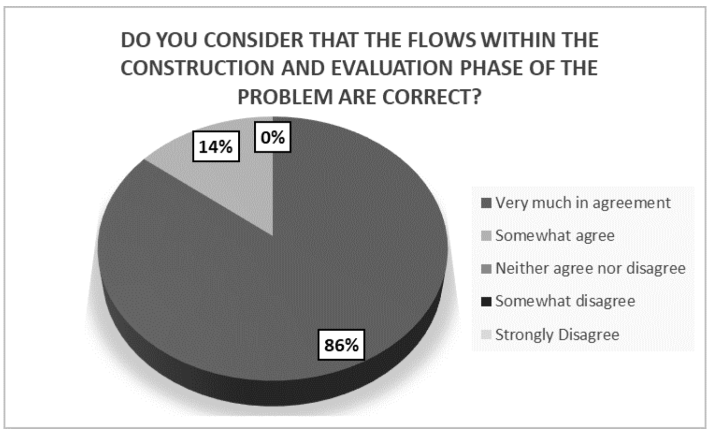

Figure C.54: Results of question 12- T3

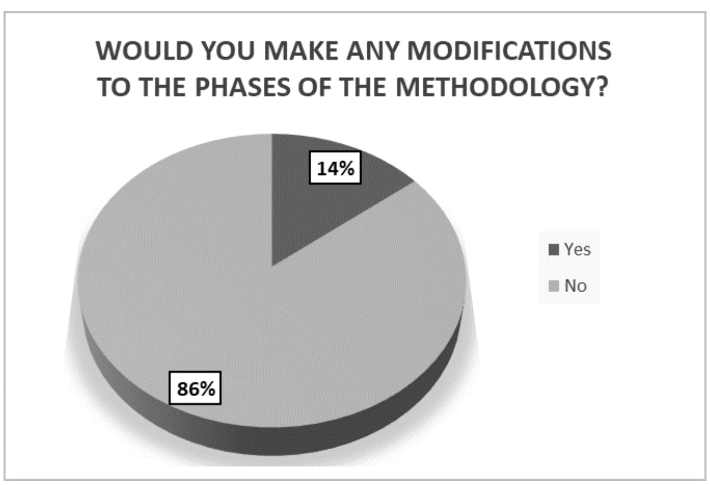

Figure C.55: Results of question 13- T3

Figure C.56: Results of question 14- T3

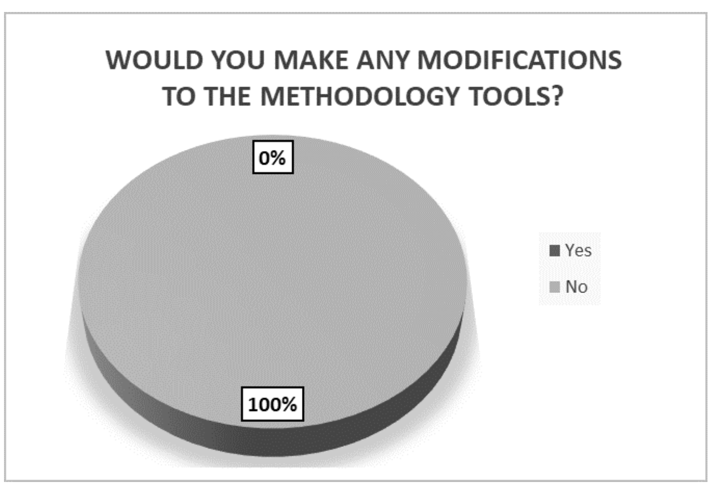

Figure C.57: Results of question 15- T3

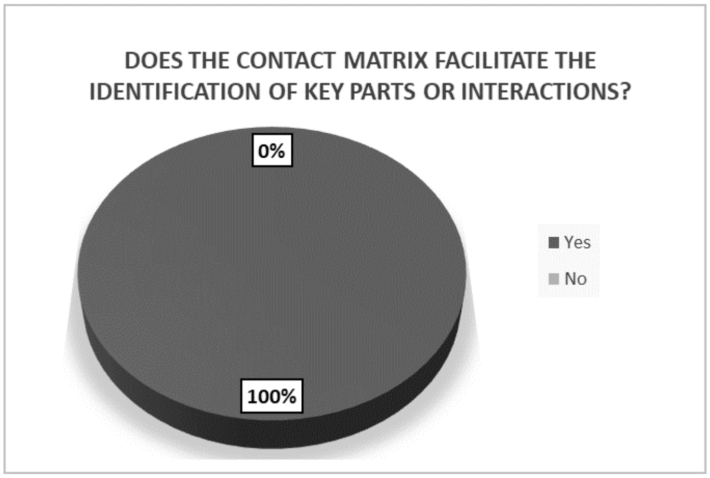

Figure C.58: Results of question 16- T3

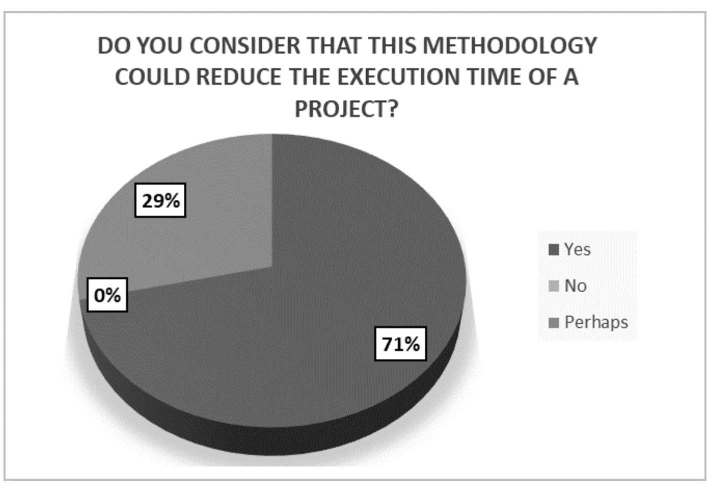

Figure C.59: Results of question 17- T3

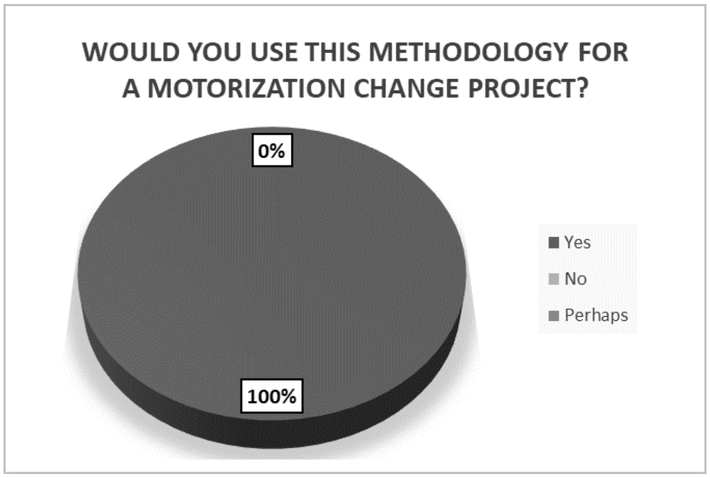

Figure C.60: Results of question 18- T3

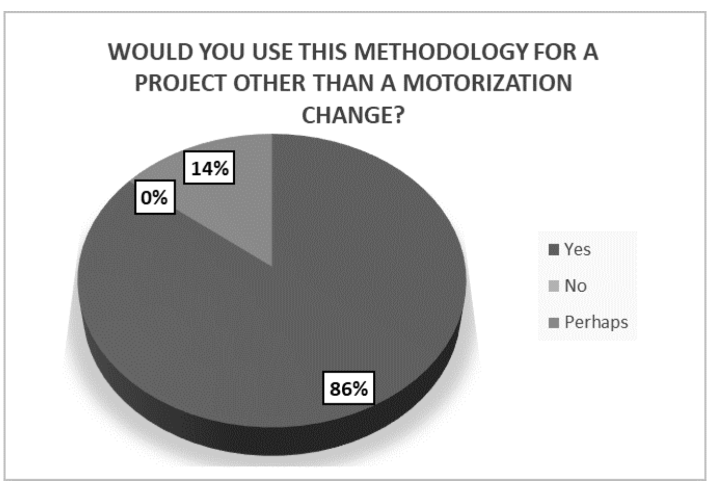

Figure C.61: Results of question 19- T3

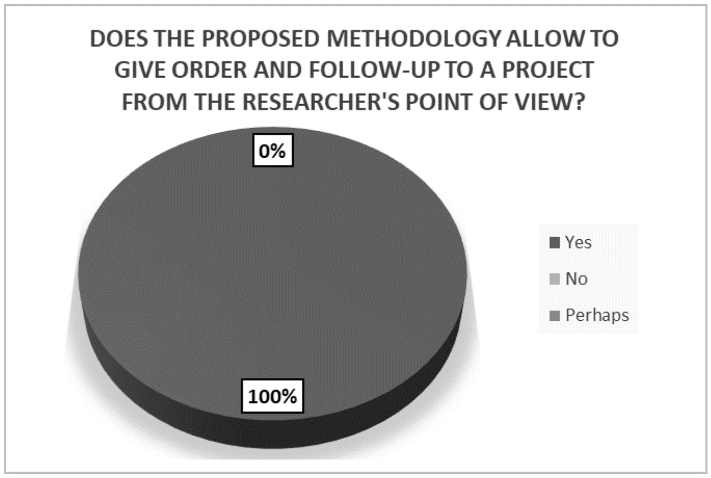

Figure C.62: Results of question 20- T3