ELECTRICALLY ASSISTED BICYCLE FOR URBAN MICRO-MOBILITY SOLUTION

Sonargaon University

A Project

by

Pial Barua ; ID BME1901017064
Md.Rabiul Islam ; ID BME1901017055
Md. Khaled Hasan ; ID BME1901017334
Nur Mohammad ; ID BME1901017127
Robiul Islam ; ID BME1901017017

Supervisor: Md.Suzauddin
Lecturer

Submitted to the
DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)
In partial fulfillment of the requirements for the award of the degree
of
Bachelor of Science in Mechanical Engineering

SEPTEMBER 2022

ELECTRICALLY ASSISTED BICYCLE FOR URBAN MICRO-MOBILITY SOLUTION

A Project

By

Pial Barua ; ID BME1901017064
Md.Rabiul Islam ; ID BME1901017055
Md. Khaled Hasan ; ID BME1901017334
Nur Mohammad ; ID BME1901017127
Robiul Islam ; ID BME1901017017

Supervisor: Md.Suzauddin
Lecturer

Submitted to the
DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)
In partial fulfillment of the requirements for the award of the degree
of
Bachelor of Science in Mechanical Engineering

SEPTEMBER 2022

Acknowledgments

Firstly, I would like to register a note of thanks to my supervisor Md. Suzauddin Lecturer, Sonargaon University for all the guidance, help and interest regarding the present work.
We would like to dedicate this thesis for the all the engineers and scientists who have given their precious time and effort for invention and building a better civilization. Also special thanks to the authority of Sonargaon University for giving us an opportunity to work on applications of mechanical engineering.

Abstract

The present work intends to build and study a prototype of an electrically assisted cycle for urban micro-mobility solution. The bi-cycle has been redesigned and modified from an urban commuter diamond frame design bi-cycle. As because the frame is solely responsible for the load distribution [1]. Electric batteries acquire enough space and also changes the vehicle dynamics of the bi-cycle. Diamond frame allow designers to easily integrates batteries [2]. The components of bicycles and electrical bicycles were studied and compared, this way we could do a correct and wise choice of components to be used in the project. Since the market already presents several different solutions in terms of this concept, it was made a study regarding some of the market available models, considering its advantages and disadvantages.
The project focused on improving market existing bi-cycle more ergonomically in affordable cost keeping the facility as much as possible. Also for future mass production, components are sourced from domestic market for existing supply chain. The project has been built for single person ride so that required parameters were calculated as per single rider weight. Later the prototype has been built with the available electric conversion kit in the domestic market. The entire frame has been designed using CAD software. Modified part was entirely built in local workshop such as seat and chain stay. The prototype has been tested physically and the result of the physical model has been analyzed and discussed. Also future scope of work has been discussed with some of this projects limitations.

Keywords: Electrically assisted power cycle, urban micro-mobility, diamond frame, prototype

Contents

List of Tables

List of Figures

Glossary

BMS	Battery management system
PAS	Pedal assist system
Pedelec	Pedal electric cycle
SLA	Sealed lead acid

Chapter 1

Introduction

1.1 Motivation

Transportation or mobility system plays a vital role for the development of any society. The first vehicle has been introduced by Nicolas Joseph Cugnot in 1769 at France [3]. The machine was first capable of human transportation powered by steam engine. Later on, sequence of development in vehicle engineering led us to use Internal combustion engines for automobiles. The transportation system improved much more than steam powered vehicles using IC engines. Today's a typical passenger car vehicle emits about 4.6 metric tons of carbon dioxide per year [4]. Besides emissions there are several limitations which led IC engine an inefficient machine for vehicles. Maximum thermal loss, inability of instant torque, using fossil fuels is making engine obsolete in coming days. Electric vehicles do overcome these limitations of IC engine, though EV has its own types of drawbacks. One of the big drawbacks is driving range, battery takes more time to restore energy in comparison with IC engine. This makes an EV shorter driving range vehicle. On the other hand, electrification is focusing on micro-mobility, micro-mobility ensures more range, economy, emission free mobility specially for developing countries like Bangladesh where rapid electrification of vehicle is challenging. This project will focus on building an electric cycle for urban micro-mobility with a sustainable existing supply chain system in an affordable price. The ongoing depression on economy and war issue lead the gas and fuel price in its peak in the history of the domestic market. In Dhaka city 16% bus fare increased and in long road 22% of bus fare has been increased [5]. This led the entire transportation costly for daily city commuting. Middleclass peoples are focusing on affordable personal mobility. When it comes the matter of personal mobility for middle class earning people, it is obviously commuting motorcycle or scooter. Keeping with the global supply chain gas and price also overall two wheeler industry increased price. Most of people are switching to electric bike, but poor service availability and inadequate supply chain with short range making it difficult for passengers to switch fully electric motorcycle. In this situation electric conversion of conventional cycle are another available option for urban passengers. Poor modification and less ergonomics makes this converted cycle unsafe. Another drawback is the price range, which is almost near to a second handed motorcycle. To convert a conventional cycle using lead acid battery costs around 25,000 BDT to 30,000 BDT [6]. In this case we have tried to build a prototype of an electric cycle that is more ergonomically designed and cost effective for urban mobility solution.

1.2 Objectives

- To design & calculate required power estimation
- To calculate range of electric propulsion
- To build a CAD model as per ergonomic approach
- To build a prototype as per design and CAD model
- To test the prototype in road and analyzing the theoretical and practical model
- To study the production cost and affordability of an electric cycle
- To understand the local market and supply chain of electric cycle
- To find the future challenge & scope for electric cycle in domestic market

1.3 Methodology

1.3.1 Frame project

The frame is the main component of a bicycle, it's the component that connects all the other bicycle parts and where these are fitted in. But it isn't just the component that connects all the parts, as it has extreme influence in the bicycle performance, safety and nearly all aspects of the bicycle. There are several alternatives to the shape and size, but the most common is known as the diamond frame, composed by two triangles as can be seen in the figure.

Figure 1.1: Bicycle diamond frame

There are several aspects to consider in the design and conception of a bicycle frame, essentially the weight, strength and stiffness. The frame need to be very strong stiff and light in weight, which is obtained by combining different materials of bi-cycle frame. [7]Also, and in this project in particular, the compatibility is very important factor.
Regarding the material for the frame, the most common and used from the beginning of the bicycle history is the steel [8], but there are several other ordinary alternatives as aluminum alloys, titanium, carbon fiber and other composite materials. All the materials present its own advantages, but it is steel the most used one, as it is strong, relatively easy to work, cheap and reliable, which makes it one of the better alternatives for this specific purpose. Aluminum, despite its lower density compared to steel even larger diameters and wall thicknesses do not result in a heavier frame [9]. Titanium, despite having a high strength to weight ratio and excellent corrosion resistance it's even more expensive and difficult to machine than both steel and aluminum. Titanium offers bi-cycle designers a material 62% stiffer than aluminum but 42% lighter than steel [10]. Also bi-cycle's frames made of carbon fiber are extremely popular for high performance cycling due to the stiffness-to-weight ratio, which enables greater power transfer [11]. We selected a bi-cycle that is made of mild-steel as it is available and cheaper.

1.3.2 Decision Method

In order to be able to make decisions in a less subjective way, we opted to use a decision method. The Pugh method or decision-matrix method is a quantitative technique widely used in engineering. The method was developed by Stuart Pugh, a British professor that worked in the University of Strathclyde, Scotland, in the fields of product design and development, engineering and management. The Pugh method relies upon a series of pairwise comparisons between the design candidates. It allows the comparison of the different alternatives through a wide number of criteria, even more, it manages to attribute different weights to the different criteria, enabling more or less importance to a specific criterion. This allows to take in consideration the importance of each of the criteria individually, taking in account our designed objective and purpose.

To apply the method, first it is necessary to grade (from 1 to 5 for example) each of the criteria, this is made by taking in account the importance that it has on the decision making. This is, a very important criterion, that has a big influence in the choice, would be graded with a five, in contrast, a criterion with little importance would be graded with a one and so on. This is referred as the criteria weight, by other words, how important and how influential this specific criterion will be on the decision making. After the criteria selected and graded according to its importance, it's time to grade how good or bad each option fulfills the criteria. This means that if an option is a good option taking in account only this specific criteria, it should be highly graded. On the other hand, if an option doesn't suit the criteria at matter, it should be poorly graded. This value thus represents how each of the options classifies in accordance with a criterion in particular. Then, with the matrix all filled up and graded proportionally, the results can be calculated. This calculation is made by multiplying the criteria weight by the grade that the option at issue got. To obtain the final result, it is necessary to sum the multiplication results from each of the criteria. Comparing the results of the sums of each option we can easily make a decision, a decision that resulted from a comparison between all the options and taking in account all of the criteria as well as its individual importance.

1.4 Thesis Outline

The present document is divided in 6 chapters, introduction included, and it is structured as it follows:

- Chapter 2 - State of art - Presents a review of electrical bicycles and its main components. It approaches electrical bicycles and a quick analysis regarding the market of the concept. It also explores and compares the models existent in the actual market.
- Chapter 3 – Calculation - Gives an inside of required power, torque and range calculation of the electric-cycle.
- Chapter 4 – Electrically Assisted Bi-Cycle components – It discusses about the all components of the bi-cycle
- Chapter 5 – Electric Bi-cycle project - Presents the overall project from material to construction
- Chapter 6 – Prototype Design – It gives an overview of the model design.
- Chapter 7 – Prototype Construction – Presents the construction details of the project bi-cycle
- Chapter 8 – Conclusions & Future Work – Gives an idea of overall project result and future scope of work

Chapter 2
State of art
2.1 Electrical bicycles

Bicycles have been around for more than two hundred years now and since then they have been one important and one of the most used means of transportation. Who invented the concept is a very controversial question and cannot be known for sure. What is certain is that they evolved a lot since its creation and still have a very important role in today's society. In 2003, more than 1 billion bikes had already been produced worldwide twice as many as the number of automobiles [12]. They not only provide a viable mean of transportation but also a very popular form of recreation. They had been adapted to lots of applications as children toys, general fitness, military and police applications, courier services, bicycle racing and several others.

An electric bicycle is a bike with an electric motor integrated used to assist the rider propelling the bike. Electric bikes typically offer two types of motor engagement: pedal assist and throttle. With pedal assist, the motor engages only when the pedals are being rotated [13]. Pedal assistant use a PAS, the motor automatically assists the driver as long as he keeps on pedaling and if the driver stops pedaling the motor will stop. The amount of assistance given by the motor is automatically adjusted in accordance with the sensors integrated in the motor, which usually measure the pedaling rate, bike speed or torque applied by the driver.
While in ergonomics it is quite challenging for an electric bi-cycle for its seating position. For a city ride usage it has to be ergonomically designed for long range usage. Although some of local manufacturers building electric cycle keeping ergonomic aspect in priority but many of the locally converted conventional to electric bi-cycle is far away from this aspect.

Figure 2.1: PAS Sensor

2.2 Market

Since the beginning China has been dominating the global market for electric bicycles, with an estimated 85 percent of all the electric bicycles in the world being sold in China. This is due to several reasons: the government made the developing in this area an official technology goal in 1991 and more recently, a large number of cities have legally banned petrol engine mopeds and scooters. Starting in the year 2000, the Chinese market began to grew up at an exponential rate, from about 300,000 sells in 2000 to an astonishing 30 million units sold in 2012 [14].

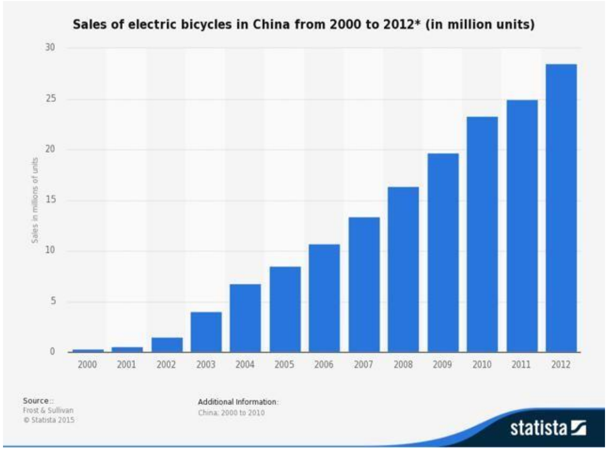


Figure 2.2: Evolution of the Chinese market [14]

In Europe and North America the market only emerged afterwards, despite the delay, the market is growing very fast and is now a multi-million-dollar industry, especially in the northern countries of Europe, like the Netherlands, United Kingdom, Germany or Belgium where there are long cycling traditions. It is estimated that in 2014 83.2% of all the imported e-bikes in the EU were imported from China [15]. Another important factor which made the e-bike market grow so much were the high gas prices in most of European countries. This merged with a growing aware of environment concerns made people start to look for less polluting means of transportation and cheaper alternatives than cars or motorbikes. One of the main drawbacks that slowed the market growth were the costs, which are relatively high compared to a common bicycle.

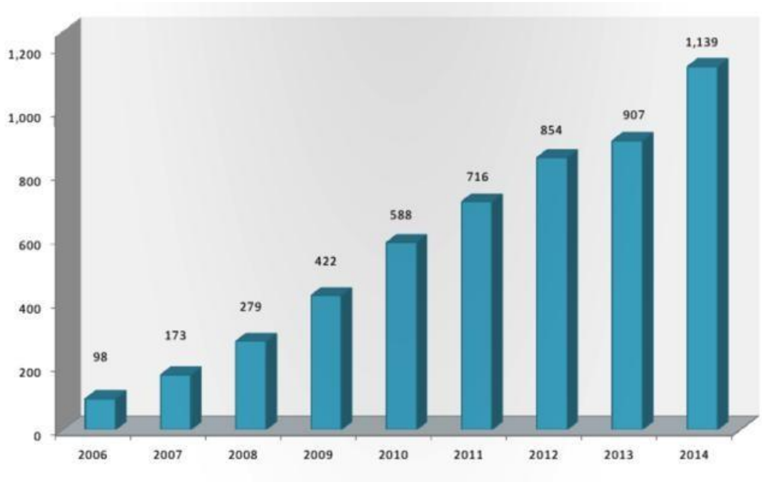


Figure 2.3: Evolution of the European market [16](1000 units per year)

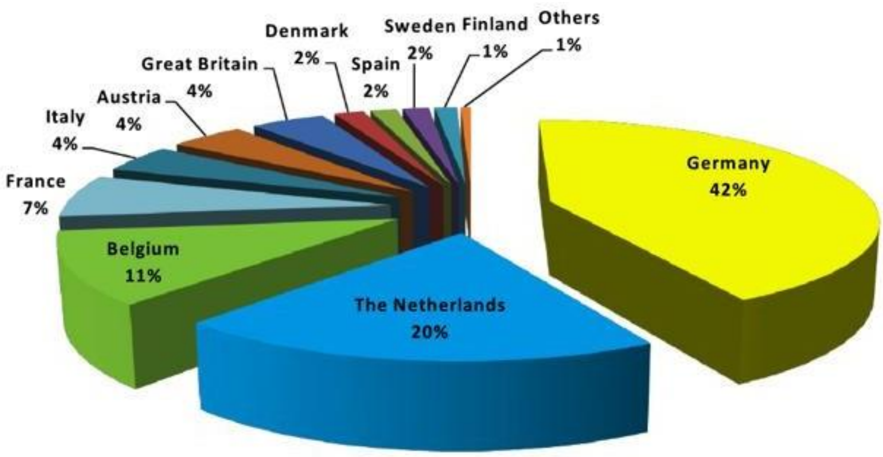


Figure 2.4: European EPAC sales in 2014 per country. [17]

According to Navigant Research, global annual sales of e-bicycles are expected to grow from nearly 32 million in 2014 to over 40 million in 2023 under a base scenario [18]. Innovative trends have contributed to the market growth and will continue to. E-cargo bicycles have started to be used as mean of transportation for several industries, post-mails, police patrolling, security companies and several others. Hybrid designs and retrofit kits are starting to appear, making the e-bike market even more attractive and as the time goes by more and more designs, with different features are surging, making EPAC's very useful and with lots of practical applications, not only in private transportation.

2.3 **Bi-cycle Components Nomenclature**

Figure 2.4: Bicycle components

1.Spoke	2. Tire
3.Rim	4. Seat Stays
5.Rear Brake	6. Seat Post Clamp
7.Seat	8. Seat Post
9.Brake Cable	10. Headset
11.Stem	12. Handlebar
13.Brake Levers	14. Head Tube
15.Front Brake	16. Fork Blade
17.Valve Stem	18. Front Hub
19.Front Dropout	20. Pedal
21.Crankarm	22. Crankset
23.Chainring	24. Chain Stays
25.Chain	26. Rear Dropout
27.Rear Hub	28. Seat Tube
29.top tube	30. Down Tube

Chapter 03

Calculation

3.1 Calculating Resistance & Drag Force

To build the project bike we need to calculate the required power and torque of the motor as per weight, top speed and expected range from the bi-cycle.

Total Kerb Weight of the bi-cycle = 35 Kg
Payload = 100 Kg
Gross Vehicle Weight = 135 Kg

Now we have to calculate total opposing force that our project bi-cycle has to overcome to ride, We are considering two major forces that will oppose our bi-cycle while riding. 1. Rolling resistance 2. Drag Force

Rolling Resistance = It is the opposing force that tends to oppose the rolling of the wheel. Also it helps to brake.

Drag Force = Drag force is the resistance of air. It depends on the speed and frontal area of the vehicle.

3.2 Calculating Total Force

As our project bi-cycle is for urban usage so the bi-cycle will mostly ride on asphalt road, we are considering the friction co-efficient for asphalt is 0.004

We know that,
Rolling Resistance, Fr= Co-efficient of friction × Gross Weight× Gravitational Acceleration
= 0.004 × 135 × 9.8
= 5.30 N

For calculating drag force, we are considering co-efficient of drag is 0.9 , density of the fluid 1.2 frontal area of bi-cycle 0.6 m^2 and velocity of the vehicle 20 Km/h (5.5 m/s)
We know that,
Drag Force, Fd = Co-efficient of drag × ½ × Density of fluid × (Velocity ×Velocity) × Frontal Area
$= Cd\, {}^{1}/{}_{2}\, \rho(vxv)A$
= 0.9 × 0.5 × 1.2 (5.5 × 5.5) 0.6
= 9.8 N (Considering 10 N)

Therefore, Total Resisting Force = (5.3+10) N
= 15.3 N

3.3 Calculating Required Power, Torque & RPM

The velocity of the bi-cycle is 5.5 m/s, total resisting force is 15.3 N and considering efficiency of motor is 0.8
Calculating required power, P = Ft × V/η
= 15.3 × 5.5 / 0.8
= 107 W (Considering 110 W)

Diameter Of the wheel, D = 0.66 m
Radius of the wheel r = 0.33 m
Circumference of the wheel, C = $2\pi r$
$= 2\times3.14\times0.33$
= 2 m
It means one revolution covers 2m in linear distance

Covered distance in one minute by drive wheel = 20 Kmh
= 20000/60 (m-m)
= 333.33 m-m
RPM of the wheel = 333.33 / 2
= 166 rpm

Gear ratio of motor drive sprocket and driven sprocket 9:18
Wheel RPM = 166
Motor RPM = 18/9 × 166
= 332 rpm

Required Torque to propel the bi-cycle = 9.5488 × Power / rpm
= 9.5488 × 110 / 332
= 3.15 N-m
Considering the top speed will reach 0 to 20 Km/h in 30 second
We will determine the value of acceleration from velocity equation,

V=u+at

Therefore, Acceleration, a = 5.5 / 30
= 0.18 m/s2

Max Force, F= Mass × Acceleration
= 135 × 0.18
= 24.3 N
Max Torque, T = Force × radius
= 24.3 × 0.33
= 8 N-m

3.4 Range Calculation:
Battery capacity = 10 Ah
Battery Discharge Current = 10.4 Amp
Maximum C rate of the battery = 10.4 / 10
= 1.04 (Considering 1 C rate)
We have calculated the C rate considering the maximum motor power 250 W. From our previous calculation we have come to know that, vehicle power required at 20 Kmh is 110 W.

As because the riding profile is not constant, frequent braking and low speed situation is common in urban environment. We have analyzed and prepared a data sheet thus represent the data in a discharging current vs C rate in a typical graphical form.

Power (Watt)	Voltage(V)	Discharge Current (Amp)	Battery Capacity (Ah)	C rate
250	24	10.41666667	10	1.041667
240	24	10	10	1
230	24	9.583333333	10	0.958333
220	24	9.166666667	10	0.916667
210	24	8.75	10	0.875
200	24	8.333333333	10	0.833333
190	24	7.916666667	10	0.791667
180	24	7.5	10	0.75
170	24	7.083333333	10	0.708333
160	24	6.666666667	10	0.666667
150	24	6.25	10	0.625
140	24	5.833333333	10	0.583333
130	24	5.416666667	10	0.541667
120	24	5	10	0.5
110	24	4.583333333	10	0.458333
100	24	4.166666667	10	0.416667
90	24	3.75	10	0.375
80	24	3.333333333	10	0.333333
70	24	2.916666667	10	0.291667

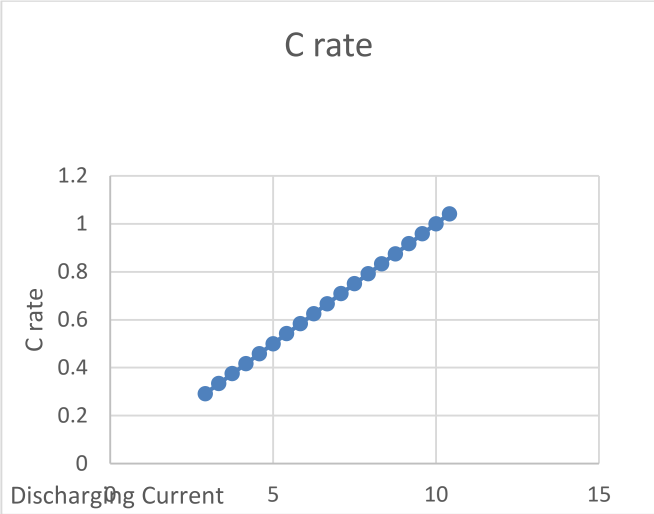


Figure 3.1: Discharging Current Vs C rate

From the above figure and table, we can understand C rate is proportional to discharging current. Higher the discharging current the value of C rate increases also from the table we can understand higher the power demand higher the discharging current and indirectly higher C rate.

Now 1 C rate indicate the discharging of the respective battery in 1 hour. The relation between C rate and discharging time is inversely proportional. From the table we can get the value of C rate 0.45 when the bicycle is consuming 110 W power. Thus the discharging time of the battery is 2.22 Hr.

If our top speed is 20 Kmh then total range in 2 hours will be maximum 40 Km.

Battery Required Charging Current, A = Ah ×10%   Battery Capacity = 10 Ah

= 10 ×10%
= **1 Amp.**

Required Single Charging Time, T = Ah/A
= 10/1
= 10 Hours

Discharging Percentage Per Kilometer = 100/24
= 5 %

Chapter 04

4.1 Electrically Assisted Bi-cycle components

4.1.1 Motor

Motor is the most important machine to propel the bike. In the context of electric conversion supply chain of Bangladesh, there are two type motor which are more available in the conversion kit market. 1.PMDC Side Motor 2. Hub motor.

Figure 4.1: PMDC Side Motor

PMDC Motor are known as Permeant magnet DC motor. These are simple in construction and easy to replace with a minimal cost in an e –cycle. Typically, these motors are mounted in one side and provide torque with a help of chain drive mechanism with drive wheel. PMDC motors are a lot smaller in size which renders them suitable for use in a wide range of applications [19]. The main advantage is it is cheap and maintenance is very easy compared to other type of motors. Also torque reduction can be easily done with this PMDC side motor. Motor can be easily dismounted whenever it requires for service or replacement as for its mounting advantage. These are also lightweight and causes less unsprang weight. As it mounted in one side, weight distribution is an issue in this case thus dynamic balance. PMDC side motors transfer less vibration from road shock as it contained in sprung weight on suspension. It also cost lower compared to many other motors in the market [20]. Using chain as a drive mechanism create more noise, harshness & vibration and requires maintenance

PMDC Side motors

Advantages	**Disadvantages**
Uses the own gears of the bicycle	Wear and tear
Consistent in steep hills	Uneven weight distribution
Light Weight	More Spare needed to transmit power
Cost efficient	More noise harshness & vibration
High torques	Less cornering balance
Less unsprang mass	
Better suited for uneven road User friendly	

Table 4.1: Advantages and disadvantages on the use of PMDC motor

Hub motors are mainly BLDC (Brushless DC) motors that mounted in wheel hub. There are two types of hub motors, geared and gearless motors, both can operate independently of the rider pedal align. Hub motor is need less maintenance as its sealed within the wheel hub but it is time consuming to replace a tire or motor as it is an integrated part of the wheel. Hub motors are costly compared to others in the market [21]. Compactness of this motor made this safer. Due to its mounting in the hub of wheel it increases unsprang weight and causing more effort of the paddler due to more drag [22]. Also it transmits more force from road shock thus affecting the cycle frame also makes the ride uncomfortable.

Figure 4.2: Example of a hub motor.

Hub motors	
Advantages	**Disadvantages**
Few moving parts - low maintenance	Drag
Possibility for both driving wheels	Inconsistent in steep hills
Wide variety of models available	Less efficient
Regenerative braking	Struggle to start in high inclinations
	Unbalance the weight distribution
	Absorbs all vibrations and shocks

Table 4.2: Advantages and disadvantages on the use of Hub motors.

4.1.2 Frame

Frame is the most critical part of a bicycle. The design of a bi-cycle is very important as it has effect on performance, dynamic balance and safety. A bicycle frame has to deal with various loads while riding. More specifically in acceleration, braking and cornering bike has to deal with sudden force to withstand.
Bicycle frames can be made out of several materials, the most common are: carbon steel, mild steel, aluminum, titanium and carbon fiber. Steel is the most common to be seen in bicycles, it has been used for a long time and is also the cheapest from the referred above. It is a strong and long lasting material. It is known to be easy to work with, in comparison with the other materials, and the tools needed to work with it are also cheaper (welding gases, welding machines, etc). One of the major disadvantages is his high density, making it the heaviest of the materials considered.
Aluminum has a lower density and lower strength compared to steel alloys, however, it has a higher strength-to-weight ratio, meaning it can build a lighter frame. Despite being more expensive than steel alloys, it is getting cheaper and very widely used on today's bicycles. It's a light, strong, durable and stiff material, making it one of the best choices for this type of application.
Titanium is lighter than steel but just as strong. The major qualities of Ti frames are its durability, damping capacity and low weight. Titanium frames usually aren't painted; this is because they don't need any protection as the material naturally resists the corrosion. Its damping capacity allows it to flex while maintaining its shape, resulting in shock absorbing and a smoother ride. The major downside is the cost. It's both an expensive material and it requires special machinery and skills to work with.
Carbon fiber has become by far the most popular material for performance road bikes. It is incredibly light, some carbon fiber frames weight less than 700g and are strong enough to be ridden to their limits in some of the toughest races in the world. The biggest flaw is that it is very brittle, contrarily to metals, it easily cracks. This is because the carbon fiber frames are made to sustain loads in a specific direction and can't out stand them in different directions.
The material from which the frame is made is very important but so does the geometry. Essentially the length and angles of the tubes, these dimensions will determine how comfortable, stable and maneuverable the bicycle will be, among other practical aspects. For bicycles there are hundreds of different designs with different features, some of the more basic and most seen shapes are the diamond shape, the step-through and the cantilever frame.

(a) Diamond frame (b) Step-through frame (c) Cantilever frame

Figure 4.3: Frame shapes

4.1.3 Wheel

Wheel is a very important component in a bicycle and its size must be selected wisely. For urban mobility of Bangladesh, the wheel diameter must be bigger due to road uncertainty. There is smooth road in some of areas like Bashundhara, Gulshan, Rampura. But for small branches roads specially in the locality of Old Dhaka, roads are not always smooth and bumps and hollows are a regular road experience. Small wheel need more torque from motor to overcome these obstacles which will ultimately discharge battery fast. Small wheels limit the mobility of the bicycle, and mobility itself is one of the major advantages of using a bicycle as a mean of transportation, especially in an urban environment as this is intended to serve. Small wheels can represent a problem to overcome simple obstacles as sidewalks or small steps. Even a small hole or stone in the pavement can be enough to unbalance the rider and create a dangerous situation, either for the rider or for the surrounding people.

Figure 4.4: Wheel size [23]

To define a bicycle wheel are required two measures, one that states the diameter of the wheel and another to define the width. The diameter is the dimension that stands out more and that has more influence in the bicycle. The standard sizes are stated in inches and there are several different sizes available: 8,10,12,16,20,24,26,28,29,32 and some intermediate sizes, usually from old or very specific bicycle designs. The smaller sizes have little applications, mostly being used only in child bicycles or wheel chairs. The 16" and 20" sizes are usually used in foldable bicycles, BMX or juvenile and light weight riders. The sizes 24" up to 29" are the are the ones with more applications in the market, being used in most of mountain and rode bicycles. 32" or even 36" sizes are rather unusual and can be seen in unicycles or some novelty bicycles.

Figure 4.5: Different wheel sizes

4.1.4 Transmission

The gears in a bicycle are what determines and allows you to change the relation between the cadence on which the rider pedals and the cadence of the driving wheel [24]. This allows the rider to properly choose the gear ratio for efficiency and comfort in accordance with the circumstances. gear systems have different gear ratio ranges and features; they must be chosen taking into account the main purpose for the bicycle. There are four main types of gearing mechanisms for bicycles: fixed gear, single-speed, multi-speed and internal gears.

Fixed and single-speed are pretty similar, both just allow one fixed gear ratio. Fixed gear was the first gear system to be used in bicycles and is characterized by having the pedals directly connected to the chaining. If the wheel is spinning so do the pedals, which allow you to brake counteracting the pedals movement. The difference between fixed and single-speed gears is that single speed has a free wheel system, which allows to cruise, without the need to pedal. These two gear systems are still in use in modern days, essentially because of the mechanical simplicity and low weight.

Figure 4.6: Fixed gear system

Multi-speed systems are the most seen gear system in bicycles, it is composed by several componets, multiple sprockets of different sizes (up to four chain rings in the front and five to eleven attached to the rear wheel), a mechanism called derailleur used to move the chain from one sprocket to another. The system is controlled by two levers in the handlebar, the left one controls the front derailleur, which provides large jumps in gears and the right one controls the rear derailleur, allowing to fine-tune the gear ratio. For example, when cycling uphill it would be easier using a high gear, a small chaining in the crankset (front) and a larger in the rear.

Figure 4.7: Multi-speed gear system

Internal gearing has all its system hidden within the wheel hub. Internal gears work using an internal planetary gearing system which alters the speed of the hub casing and wheel relative to the speed of the drive sprocket. They have just a single chaining and a single rear sprocket. Internal gear systems are available with between 2 and 14 speeds. This is a system that goes easily unnoticed once all its components are hidden inside the wheel hub. It is very advantageous for a metropolis environment as it enables the gear change even when the bicycle is stopped, no other gear system has this feature.

Figure 4.8: Internal gear system

4.1.5 Batteries

The battery is the heart of any electrical bicycle. The motor is useless without all the energy that is stored in the battery. It is one of the hardest components to come by and often the most expensive. Being a crucial component in any electrical bicycle, its choice must be made taking into account the purpose that the bicycle is designed for, as well as the range we're aiming for. Of course, it also has to be in compliance with the other components of the bicycle, as the controller, the motor and all the electrical components that make up the bicycle. The three most common types, and most used in electrical bicycles are lithium, nickel and lead acid batteries, each one with several advantages and disadvantages.
Like the others referred, li-ion batteries are rechargeable, the lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. They are used in most of the laptop batteries, cellphones, electrical vehicles like Tesla's Model S and several other applications. They can be found in different sizes and shapes, all commonly referred as li-ion batteries, a nomenclature that represents a whole class of batteries.

Figure 4.9: Examples of different lithium based batteries

There are several combinations of material and different chemistries of lithium batteries available in the market and as days go by more and more appear, with different and somehow better characteristics. Here we will be describing what can be considered a small share of the market alternatives, even though, these are some of the most used and well known alternatives, especially in the e-bike industry:
Lithium Iron Phosphate ($LiFePO_4$) - Were one of the first widely used in the e-bike industry and are still one of the most used in this kind of applications. This type is the one that provides the longest lifespan among the other li-ion batteries, rated at 2000 charge cycles or even more. In comparison with the other li-ion batteries these are the safest, their chemistry makes them inherently safe and almost fireproof. They are also some of the largest and heaviest in the li-ion class. One drawback is that most of them have discharge rates relatively low, so they would not be suitable for high powered electrical bicycles, non the less they are very suited for a standard every day bike. These cells also need a protection circuit, usually called Battery Management System (BMS). This is used to keep the cells from becoming unbalanced or over charged or discharged during the successive charge and discharge cycles. Most lithium type batteries need this protective circuit otherwise they can become dangerous and its life expectancy abruptly reduced.

Lithium Manganese Oxide (LiMn2O4) - This type is a good middle ground in nearly all regards among the other li-ion batteries, in terms of size, weight, safety and cost. The main downside is its lifespan, which is relatively low considering the other lithium type batteries, generally allowing only 600-800 charge cycles. Despite handling a more balanced charging and discharging, most of the battery packs come along with a BMS.

Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) - This type is relatively new in these kind of applications. It became popular around 2013-2014 but is rapidly taking over the electric bicycle industry. They have a safe chemistry that can deliver high power in a lighter and smaller package than the two types referred before. These batteries are also commonly preferred for electric vehicles due to its very low self-heating rate.

Lithium Polymer batteries (*LiPo*) - These are the smallest, cheapest, lightest and most powerful of the lithium batteries described. But they have several disadvantages, including short lifespan (a couple hundred charges) and propensity to combust into giant fireballs. This is due to its unstable chemistry and if they're not carefully and correctly handled, when over-charged or over-discharged, punctured or dropped they will ignite and burst into flames. Basically, they have to be treated with much care, otherwise can became very dangerous and in this specific application, where they are meant to be used near the rider, or even between its legs, they are not a safe choice. These are widely used in the remote control industry, in cars, airplanes and more.
Nickel batteries are another type of rechargeable batteries available in the market. These predate the lithium batteries and are mostly used in portable equipment's as power tools, flash lights, electric vehicles, remote-controlled devices, among others. They have gain its popularity as a replacement for the lead acid batteries, presenting much better qualities than these. Even though, lithium batteries had replaced them in most of its uses and applications. They have a low lifespan and have to be treated carefully, both on assembling and charging.

Figure 4.10: Examples of different nickel based batteries

There are two main chemistries of nickel batteries:

Nickel Cadmium (*NiCd*) - This is the oldest type, they were invented in 1899 but only started to be widely used around the 1960's. Nowadays, they have less uses as they were replaced by *NiMH* and lithium batteries, also, and one big drawback, is that cadmium is a very hazardous substance and can be dangerous to people and the environment. This led the governments to introduce very restrictive laws and normative surrounding this battery type, nowadays most landfills won't take them or require paying an extra fee. It is not a battery type very suitable for low powered electrical bicycles as they have a high rate discharge capacity. Also, these can experience what's called the" memory effect", in which it is required for the battery to be totally discharged before charged, otherwise after some life-cycles, the batteries will gradually lose their maximum energy storage capacity.
Nickel Metal Hydride (*NiMH*) - This is a battery type that was developed after nickel cadmium batteries, it was first patented in 1986. They are very similar to *NiCd*, the main difference is that instead of cadmium, hydrogen is used as the active element and thereby, it is environmentally friendly. Comparing to the rechargeable *NiCd* batteries, these have a higher energy density per volume and weight (40% more). Their lifespan is about 3000 cycles, being that it can vary accord-

ing to the manufacturers or the battery type. This battery also suffers from the” memory effect”, even so not as pronounced as in the NiCd batteries. Regarding the costs, they are considerable cheap, usually about half the cost of lithium batteries.

Another option would be the Lead Acid batteries, the oldest between the three battery technologies described before, dating from around 1860. Despite being an old technology, they are still experiencing constant innovations and still being widely used worldwide. It is the same type of battery that you would find in most fuel cars, which makes them widely available and of easy access. Are much cheaper than Li-ion or nickel batteries and this is mainly due to the weight and capacity, they weigh twice as much as nickel batteries, and three times as much as lithium batteries (low energy-to-weight and low energy-to- volume ratios). One important feature that has to be guaranteed, especially for this kind purpose, is that the battery has to be what’s called a Sealed Lead Acid (SLA), otherwise, the acid might start leaking from the battery and create a dangerous situation.

• (b)

Figure 4.11: Examples of different lead acid batteries

4.1.6 Throttle/PAS

In this section we will be describing the alternatives to control the amount of motor assistance. It is a very important feature and with the right control you can either use the full potential of the motor or use little help from the motor, majoring the possible range. There are two main ways to control the assistance that the motor gives to the rider, both allow to manage the amount of assistance that is desired with some differences.

Throttle - The concept is pretty much the same as in a common motorcycle. These allow to directly control the amount of power that the motor is producing in real-time. There are several types, as thumb throttles (the throttle is engaged by pushing the lever forward with your thumb), full twist throttles (the throttle is engaged by twisting the throttle grip, seen in most motorcycles) or half twist
throttles (the throttle is engaged by twisting the throttle grip, which is this case is just half of the grip. These are the most common throttles used in e-bikes).

Thumb throttle (b) Full twist throttle (c) Half twist throttle

Figure 4.12: Types of throttles

Pedal Assist System (PAS) - Also referred to pedelec [25] (pedal electric cycle), is a mode that provides power only when the rider is pedaling, the motor will stop if he stops pedaling or if he actuates the brakes. The amount of assistance is managed in a electronic circuit and takes into account information given by a torque sensor, a cadence sensor and a speed sensor (not all models have the three types of sensors combined). The faster the pedal cadence, the faster the controller will make the motor spin, the same with the torque sensor or a speed sensor. The cadence sensor measures the pedal revolutions per time, you could be pedaling very lightly or very hard and it will provide the same level of assist. It is mounted in the bicycle frame and one or several magnets are mounted in the crank, measuring the revolutions made by the crank. The torque sensor is usually mounted on either the pedal crank or near the rear dropout and it measures the amount of torque being applied by the rider on the pedals. The speed sensor is usually mounted in the bike spokes; it works with the same principle that the cadence sensor but measures the bicycle actual speed.

(a) Torque sensor (b) Cadence sensor (c) Speed sensor

Figure 4.13: Types of sensors

The control of the inputs from the sensors is made so that the output is the most desired for the rider, of course that with information from three types of sensors instead of just two makes it easier. It’s a much more intuitive control mode compared to throttle, as it doesn’t require to activate anything, just to ride the bicycle as a common bicycle, the only difference is that it will feel like cycling with constant tail wind. Most pedal assisted bikes allow to choose between different levels of assistance, low medium or high for example.

4.2 Comparative Analysis with Existing Model

In this section we will be paying attention to the varied offer of electrical foldable bicycle designs that exist in the market. It will allow us to have a more extensive comprehension of the alternatives that the mar- ket offers, highlighting its main features, vantages and disadvantages. The models selected are some of the most common and most seen designs but also some of the newest and cutting edge-designs. Of course, and due to the large variety and possible designs in the market, this selection is quite brief, therefore the model selection was made trying to address some diversified alternatives in today's market.

Figure 4.14: Ride 701 Premium [26]

The first model in consideration is the Ride 701 Premium. Its seating position is as same as the conventional bi-cycle and also the handlebar. Its motor is inserted in the rear hub and has a power of 350W that combined with a battery of 36V and 13.5Ah leads to a range of approximately 35 Km and top speed 35 Km/h. The battery is settled in the back part of the seat tube. The price of this bi-cycle is 48,000 BDT.

Figure 4.15: Ride Eco Plus [27]

The Ride eco plus is the most ergonomically designed electric-cycle in the domestic market. Its saddle height is low compared to others and it does not have any top tube that makes it a uni-sex frame. It has been powered by a 350W hub motor with a battery of 36V and 13 Ah that leads to range of approximately 40 Km and top speed 30 Kmh. The battery is settled with the seat tube. The price of the bi-cycle is 37,000 BDT.

Figure 4.16: Locally converted electric cycle

Although locally converted electric cycle does not have any standard but we have taken a model which is mostly being converted by the conventional bi-cycle user. It has lead acid battery of 24 Volt and 250 W PMDC side motor. It costs almost 25,000 to convert a conventional bi-cycle to an electric model. Range of these cycles lies between 20-25 Km.

Table 2.3: Comparison and analysis of the existing models

Model	Main characteristics	Mounted	Advantages and disadvantages
Ride 701 Premium	250W rear hub motor PAS is available 36 V Li-ion Battery Top Speed 35 Kmph Range of 35 Km Costs 48,000 BDT		Highest Range, highest top speed. High cost, not ergonomically designed.
Ride Eco Plus	350W rear hub motor PAS is available 36 V Li-ion Battery Range of 40 Km Top Speed 30 Kmph Costs 37,000 BDT		Highest range, pillion seat, better ergonomics. High cost, small wheel.
Locally Converted Electric Cycle	250W pmdc side motor PAS is not available 24 V Lead Acid Range of 25 Km Top Speed Costs 25,000 BDT		More option for modification, lead acid battery is not efficient. No ergonomics design.

Table 4.3: Comparison between existing models

Chapter 5

5.1 Electrical bicycle project

To build a state of the art electrical bicycle, a concept design and with features that would be able to di- rectly compete with the concurrence and the current innovations that the market is presenting nowadays is not an easy task. It requires a big monetary investment and a considerable amount of time, more than the available for this type of project. Also, it would require the access to state of the art materials, building methods and machinery, as well as specialized and skilled manpower. Thus, and once that we will not be able to overcome this obstacle or at least some of them, we will be conceiving two different designs.

The first design, from a concept projected from scratch and with the objective of creating a unique electrically assisted power cycle. This one was projected without paying close attention to the obstacles referred before, this is, considering a larger delivery limit, as well as enough financial investments and access to building methods, machinery and specialized manpower. Even so, we've tried to use relatively common and of easy access materials and building methods. With this, our intention was to design a electrically assisted bicycle that would be able to compete with the current market but more importantly that would be able to fulfill all the needs and requirements that we've assumed necessary for a bicycle designed for this specific application. It is important to note that this design presents just a base case, it still needs to be tested and refined in order to achieve a good and reliable final product.

Once that we wouldn't be able to build a prototype suchlike, we will have to consider an alternative design within our range of possibilities. For this design, we will try to maintain the main features and the best characteristics of the first one. It should be as close as possible to the one we've conceived from scratch but within our chances, in order to build a fully working prototype. This prototype is intended to be built using other bicycle parts and adapt them to obtain a testable and usable prototype.

In this section, after defining the main requirements for the project, we will be presenting both the designs, defining their main features and choices that we had to make for each of the components, as well as the reasons that made us took such decisions. Also, we will be evaluating the main differences between both designs and what practical consequences these changes would have in the use of the bicycle.

5.1 Project Requirements

Projecting a vehicle has several factors inherent to it, even more, if the vehicle is designed for a specific purpose and application as it is in this work. Therefore, it’s important to define some base requirements, despite some do have more importance than others. We will be defining its main requirements and objectives that the vehicle has to be able to show or to achieve during its normal use:

Autonomy - It is a very important factor in any kind of vehicle, but especially in an electrical one, as it limits the range and reduces the possibilities for the rider. Also, recharging the battery is not an instantaneous process, and it is necessary to use the battery charger and a power outlet, in other words, if the battery fully discharges during the path, it cannot be charged without specific conditions and instruments. We’ve considered that the bicycle has a specific purpose of concept, two daily routes and a constant route, house-work-house or house-public transport-work and re-turning home again.With this in mind, we defined a minimal autonomy of 25 km, considering that it would be enough for the daily routine or to be able to cover more distance in case of need. This autonomy can be easily enlarged by having two sets of batteries, one substitute to replace the other as it discharges, or by using a bigger battery with higher capacity, but bigger capacities lead to bigger and heavier batteries which collides to the weight requirement.

Weight - It is an important requirement and one that it’s commonly used to characterize and evaluate bicycles. The bicycle has of course to be as light as possible, but we have to keep a realistic mind, once we are limited by the building processes available and building materials we won’t be able to build a really light bicycle compared to the today’s market. Nevertheless, the weight will the top most priority for us in every aspect of our bike.

Safe - As in every vehicle, the safety is an important and crucial requirement, all the project must be designed and conceived taking into account the rider safety and the safety of any bystanders, as the bicycle is designed to be used in public environments.

5.2 Conceived design

5.2.1 Component and material selection

Motor

The motor is a crucial component in an electrical bicycle, therefore its choice must be made carefully and thoughtfully. To choose the most suitable motor we must take into account the bicycle components as the frame, wheel size and gear system. Equally or even more important for the motor selection is the purpose that the bicycle is supposed to be applied in. For instance, a bicycle designed to be used in a urban environment as a mean of transportation has very different set of characteristics and features compared to a bicycle designed to be used for weekend rides or to ride in off-road terrains.

As explained in section 2.5.1, there are two types of motors available in domestic market: pmdc side motor, hub. Both presents their own advantages and disadvantages and are better suited for different purposes and environments.

The choice of the motor type remains now between side motor and hub motors. There are both con- side red good options and to be the best alternatives for the purpose in question. Each one presents its own advantages and disadvantages and in order to be able to contemplate all the criteria that affects this choice we will be appealing to the Pugh Method. With this, it is expected that we will be able to do a thoughtful and justified choice between both alternatives.

First it's important to define the criteria that is meant to influence the motor choice, as well as the weight and importance that each of the criteria presents according to the bicycle's purpose and range of applications. For this study, we've considered 9 different criteria, each one rated from 1 to 5 (1 being less important and 5 the most important), according to the importance that it presents on choosing the best alternative for the motor.

Weight – Weight is an important factor for a bicycle. It has an influence in total bi-cycle weight. Also the motor position. In this case Hub motor is considered 4 and Side motor is 5. In the case of position, hub motor increase more sprang weight as it mounted in the hub of the drive wheel and side motor mounted on frame.

Mass center - This criterion focuses in the influence that the mounting position of the motor has in the bicycle mass center. As referred before, the motor usually represents 25% of all the bicycle weight, therefore it has a strong influence on the bicycle mass distribution. The localization of the mass center of the bicycle or the rider and the bicycle, considering it as a whole, plays an important role on how the bicycle handles and behaves when riding it. Thus is also one very important factor for the motor choice. Hub motors are mounted in the wheel hubs, this takes the mass distribution closer either to the front or the rear wheel, depending on which wheel it is mounted. Considering that our objective, concerning the mass distribution, is to have the mass center as low and centered in the bicycle as possible, this is not the best option, specially taking in account the mid-drive alternative. This type of motor, as it was explained earlier, it is mounted near or in the crankset, which is considered to be the best position to be placed, once it lowers and centers the mass center. Given this, we've attributed 5 to the hub motor and 1 for the mid-drive alternative.

Criteria	Weight (5)	Mass Center(4)	Performance (4)	Driving Control(4)	Cost (4)	Wear & Tear(3)	Climbing Capacity(3)	Exposure (3)	Ease of transformation(1)	TOTAL
Hub Motor	4	5	2	3	3	4	2	4	3	105
Pmdc side motor	5	1	4	4	5	2	5	3	5	116

Table 4.4: Pugh Method or Decision Matrix

Performance - Regarding the performance, pmdc side motors are able to achieve better results and with higher toques. This is mainly because they can transmit more power, as it is directly transmitted to the chain, allowing them to work with the bicycle own gear system. By contrast, hub motors are mounted in the wheel center, compelling the motor to do more effort to obtain the same output. Hub motors aren't able to achieve the same torques that side motor systems do, also because if they did, and considering a front hub motor option, a motor with big torque rates would make the front wheel spin and lose traction. Given this, we've attributed 2 to hub motors and 4 to the side motor.

Driving control - This criterion focuses on the influence that the different motors have on the handling characteristics of the bicycle. With a pmdc side motor, the bicycle will be operated virtually the same way that a common bicycle would be, keeping it simple and near unchanged. This would make the bicycle more user-friendly and not requiring any extra skill than knowing how to ride a common bicycle. Using a hub motor can change the bicycle a bit, using a motor in the front wheel would make both the wheels driven, this could lead to big changes in the way that the bicycle feels, moves and rides, therefore it would require more attention and skill by the rider. This option would thus be less user-friendly and require more from the rider, therefore, we've attributed 3 to hub motors and 4 to the mid-drive alternative.

Cost - Regarding the costs, side motors are relatively more cheap than hub motors. The different cost rates are mainly because side moto nowadays is widely available on the market. Hub motors were classified with a 3 and side motors with a 5.

Wear and tear - This is a criterion that despite showing no influence at first in the bicycle, after some use it can reveal to be problematic and generate some extra costs. Of course there are measures to prevent or reduce as much as possible the wear and tear, a constant lubrication and inspection on the components that suffer major wear and tear can prevent or predict accidents. Hub motors have all they components confined inside the hub and few moving parts, this results in virtually no tear either on the motor or the bicycle components. Pmdc side motors have more moving parts and as known, they transmit their power through the bicycle components, chain and chain rings, therefore this system requires more maintenance and leads to higher wears on some of the bicycle components. Being so, we attributed 4 to the hub motor and 2 to the pmdc side motor alternative.

Climbing capacity - Climbing capacity defines the capability for the motor to overcome steep terrain. It can be an important feature in this type on bicycle, depending on the city that it will be used in. Hub motors are known by struggling or even failing in steep hills, revealing low capacity to overcame such obstacles. This is mainly because this type of motors is made to operate at a fixed ratio, making them more trustworthy to operate in flat terrains and with some speed. On the contrary, pmdc side motors can easily overcame steeps hills, being able to produce higher torques. This added up to the fact that these work and take advantage of the bicycle own gear system, makes them the best choice in what matters to performance in uneven terrains. Given this, we've attributed 2 to hub motors and a 5 to the pmdc side motors.

Exposure - This criterion takes into account the impact that the motor has on the bicycle aesthetics. Hub motors, can easily go unnoticed, as they are disguised in the center of the wheel. As for the side motor, it doesn't go unnoticed so easily, never the less, and depending from model to model they can as well go unnoticed. Being so, we've attributed 4 to hub motors and 3 to the side motors

Ease of transformation - This factor measures the easiness that each of the motors types presents to be mounted in the bicycle. Pmdc side motors are usually easier to mount, as it simply need to change the motor only. Regarding hub motors this can require more work. Even so, there are side motors in the market that are relatively simple to mount and that allow transforming almost any common bicycle into an electrical one. Given this, we've attributed 5 to side motors and 3 to hub motors.

After this extensive analysis and taking into account the results of the decision method, 105 for hub motors and 116 for pmdc side motors, we can conclude that the best alternative for the motor would be a side motor system. This doesn't mean that hub-motors are bad systems and don't make a good solution to electrically propel a bicycle, on the contrary, they are a good solution and it is a system that is" tried and true". Even so, for this specific range of applications and taking in care the criteria selected in the decision method, side motors should be a better choice to fulfill our requirements.

Figure 5.1: Drive units

Battery

Regarding the battery and once the frame would be made out from scratch, our intention would also be to build the battery pack. This would allow us to customize the battery pack shape and adapt it to better suit the frame and, as explained earlier in the chapter, the battery pack is supposed to be inserted in the inside of the frame, this would make it go unnoticed in the assembly. All the battery wiring and connections to the motor would also be placed inside the frame, disguising it and making it non visible from the outside. One thing that is common to all batteries is that more power and more storage capacity results in more weight and volume. Therefore, we have to find the best suited solution, in order to keep the bicycle with enough range and light enough to serve the purpose that it is meant to do. First, the choice relies between the three major types presented: Li-ion, Nickel or Lead acid batteries. Lead acid batteries, being the oldest type among the others, is also the type that presents less advantages and more drawbacks. They are considerable more heavy and large than whether lithium or nickel batteries, and as said before, weight and volume are major factors in this project requirements. They also present life expectancy's much more reduced, as they usually only allow up to 500 charge cycles. With respect to the power transmission, lead acid batteries have less efficiency, they present energy losses whether when charging or discharging, contrarily to lithium batteries with efficiencies close to 100%. Another major drawback in the use of lead-acid batteries is that their voltage throughout the discharge cycle drops consistently, this not only effects the riding conditions, as the bicycle loses power as the battery is discharging but can also lead to problems with the other electrical components, as the motor. With respect to the choice between nickel and lithium batteries, the primary difference between them lies in terms of energy storage: nickel has a lower energy density than lithium, resulting in a larger and heavier nickel battery compared to a lithium-ion battery with the same power and energy storage capacities. Lithium batteries present several advantages when compared to nickel batteries.

Lithium batteries have longer life expectancy's, are more efficient, have higher voltages outputs, recharging times are considerable smaller (requiring around up to 70% less time to fully recharge, depending on the batteries). In addition, nickel batteries require being totally discharged before charged, otherwise they can experience the memory effect: after being repeatedly recharged when only partially discharged, batteries gradually lose their maximum energy capacity. Still, lithium batteries also have disadvantages, they are more expensive than the nickel chemistry's, require an extra component, a protective circuit, also known as BMS (battery management system) as explained in the previous chapter. In regard to the environmental impact, whereas lithium batteries are safe and have nonhazardous materials, the same cannot be said about the nickel chemistry's, in particular the (*NiCd*), these batteries contain between 6 to 18% of cadmium, a toxic heavy metal. These require thus special care during battery disposal and is some countries, as the United States, part of the battery price is a fee for its proper disposal at the end of its service lifetime.
After this analysis, and taking in account both the advantages and disadvantages of the three battery types considered, the choice is quite obvious: lithium batteries are better suited for the kind purpose that these are meant to do. Yet, lithium batteries have several variations and material combinations, thus we have to choose the most appropriated chemistry and format for the battery pack. Taking in consideration the attributes and formats available of each of the lithium batteries chemistry's, we have chosen the Lithium Manganese Oxide ($LiMn_2O_4$). This is the most commonly used lithium battery
chemistry in the electric bicycle industry. It is a battery type that is widely available in the market and
presents good characteristics in general, as its size, weight and cost. This chemistry is also one of the safest from among the other lithium battery alternatives. Regarding the battery selection, we decided to use the Geekay Li-ion battery.

Figure 5.2: Battery

Wheels

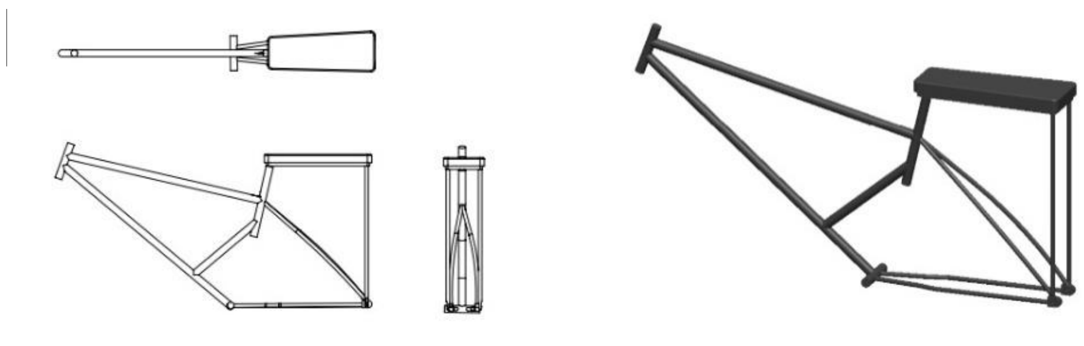
As referred before, wheels, and the wheel size has a big influence in the bicycle. They have a big impact on how the bicycle handles, rides and how comfortable and smooth the bicycle feels. Once one of the main objectives is to reduce the volume occupied by the bicycle as much as possible, we should opt to choose a small wheel size. Even though, small wheels reduce the bicycle maneuverability and make it hard or dangerous to overcome obstacles. Thereby we've chosen 26" to be the best suited size for a bicycle with this type of applications. Its size is enough to keep the bicycle compact and big enough to overcome the obstacles in urban areas.

Transmission System

Regarding the gear system to be used in the bicycle, we first must choose which of the systems are better suited for this kind application. There are four alternatives, as it was presented in section 2.5.4, fixed-gear, single-speed, multi-speed and internal gearing. Among them we have chosen the fixed gear ratio system for its simple and low weight advantages. Although in-terms of peddling and electric motor assist the ratio is difference.

5.2.2 Model description

In this model, despite all its components are represented in the 3D model, only the frame was modeled in the CAD program and intended to be built. This frame was thought and projected with the intention of fulfilling our project requirements and as said before, to create a viable and better solution as a mean of transportation in urban environments.

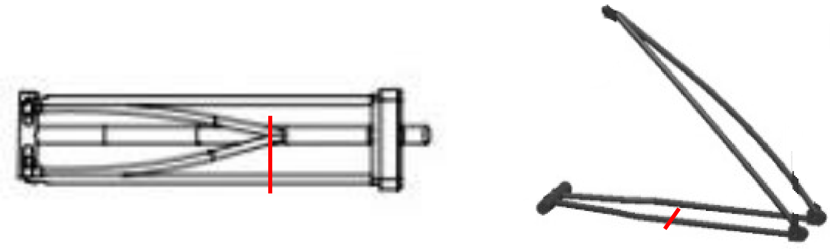


(a) (b)

Figure 5.3: Conceived design

Since the frame was the only part designed to be built and conceived from scratch, it was engineered taking in account the standard measures and usual components in bicycles. Thereby making easy to find and adapt the remaining components to the frame, components as the wheels, seat and seat post, headset, fork, stem and braking system. The frame is all made out of steel. As we have noticed in local conversion bike keeping the battery pack center of mass is bit challenging so we have customized the designed to keep the battery pack in the center of mass and also enlarged for better mounting of the battery pack. We've also imp roved the ergonomics of the bi-cycle by designing a seating position with comfortable handle. Using the virtual model this system cannot be truly tested. To know how it will behave and if it will play its role, it has to be tested and tried.

The distance between both chain strays has been enlarged 90mm to hold the battery box. The total weight of the seat and welded chain and seat stray is 7 kg total.



90 mm

(a) (b)

Figure 5.4: Folding position for transport

5.2.3 Cost estimation

In this section we will predict the cost of production that this specific bicycle would have. However, it cannot be precisely predicted as some costs, such as building processes, manpower, among others cannot be estimated with precision. Even so we will try to be as precise as possible and conservative with the unpredictable costs.

The production costs of this model can be divided in three groups: raw material, cost of manpower and costs of the components. Regarding the raw material to build the frame, and since the projected frame used mainly standard size materials, we can make an estimation on the costs for the raw-material. For motor 5500 BDT cost. The manpower costs are difficult to predict with precision, the time for the frame to be built can't be anticipated as it may vary widely, depending on possible and probable building problems that may occur during the procedure. For the prototype the service cost 3000 BDT. In terms of the components these include:

Table 5.1: Component costs

Component	Price (BDT)
Motor	5500
Battery pack	8000
Frame & Wheel	10000
Handle	1200
Seat	400
Battery Box	1500
Service	3000
TOTAL	29600 BDT

Thereby, the total cost for building and assembling the bicycle, considering generic prices for the components, will be around 29,600 BDT

Chapter 06

6.1 Prototype design

In this section we will be describing the model that we've designed to be built and to create a fully working prototype. Describing and justifying what choices we had to made regarding the model components and describing its main features and characteristics. Since we had to depart from a frame already built, we opted to use a frame and components from an old bicycle. We've tried to maintain its basic aesthetics and classic appearance. This way we intend to build a cheap prototype that keeps its classical and old appearance but restored and improved. This way the final result will create a bridge between new and old technologies in order to achieve a better outcome.

6.1 Component and material selection

Frame

Due to our project limitations, as referred before, we will not be able to build a fully working prototype as the one we've modeled and presented early. Therefore, in this section it will be presented an alternative design, considering more viable and realistic alternative choices taking in account our limitations. Never- the less, this prototype will be engineered in order to try to maintain the conceived design main features and advantages. It is intended to be built from other bicycle components and adapt them to fulfill our needs and meet the project requirements. Since we will have to stem from other bicycle components we've opted to use old bicycle components, lowering the costs and creating a product with an antiquate aspect but even so modernized and improved with the actual technology.

Figure 6.1: Original bicycle

The frame is chosen from a conventional bicycle.

Motor

Regarding the motor, the choice remains to be a pmdc side motor. But here, instead of using a motor that requires an adapted frame with special mountings, and since we are building the bicycle from an already built frame, we will opt to use a pmdc side motor to be mounted on the left chain strays. This way it can be easily fitted in the frame, requiring little alterations to it.

Figure 6.2: Selected motor

The motor chosen was from the Geekay manufacturer, a relatively reputable manufacturer among the e-bike market. It weighs 3 kg, has two types of sensors: speed and cadence. It uses 24V and 250W to power the bicycle. It can produce torques higher than 80 N and efficiency higher than 80%. The motor has come with a controller with built in BMS and PAS and it comes along with the kit.

Battery

With respect to the battery pack, we've opted to buy a battery pack already built and comes with Geekay conversion kit. This decision was made due to several reasons: the limitations regarding building processes and machinery, building a battery pack as we described in the conceived design requires a spot welder machine to connect the batteries, a battery management system as well as skills and knowledge to build a viable product. Also, another main advantage of building a battery pack was that that way we could manage its dimensions and fit it inside the frame. Since we are not building the frame and the chosen frame doesn't have capacity to store it internally, we wouldn't take much advantage on building a battery pack. The battery pack was thus chosen taking in account our project requirements, mostly the range and weight. The battery pack chosen comes along with a battery box which can be fitted in bicycle frame. The battery with controller remains enclosed in the box The battery can be easily removed from the box. The box is also locked with the key of the electrical system preventing it from theft.
Regard its capacity, 24V and 10Ah generate 240 Wh ($24V \times 10Ah = 240Wh$) Considering the same calculation method used to predict the battery pack range: $240\ Wh \div 250W\ c\ 0.96\ h$, [29] this is, the motor will be able to run for approx. 1 hours in one charge. Considering a medium velocity of 20km/h, the expected range will be around 20 km ($20km/h \times 1 = 20km$). As said before, this method to calculate the range is conservative and represents an approximation, as the range is affected by several other factors than the battery pack capacity.

Handlebar

The handlebar in the original model was straight. We have replaced the handle with a customized one to cope with the seating position of the rider.

Figure 6.3: Handlebar

6.2.1 Model description

Most of the bicycle components are from a steel alloy and the handlebar set is from steel. The frame alone, like it is represented in the figure below but excluding the wheels and counting with the seat and seat-post, weights roughly 20 kg. Considering the components missing, mainly the battery pack and the motor, the weight of all the bicycle assembly should be around the 35 kg.

Figure 6.4: Assembly of the model

Chapter 7

7. Prototype Construction

In this section we will be describing the construction processes that led to the final prototype, presenting the main difficulties that we've came across, the alterations or adaptations that we had to make to the components and the processes used to do it.

7.1 Major difficulties

Along the building and mounting process we came along with some difficulties. This biggest problem was due to the frame, as it is an old frame, some of its dimensions aren't standard, requiring adaptations to make the components compatible. One big problem was to find components that could be fitted to the bicycle dimensions and fixation points. Components as the rear wheel hub was difficult to find. Still, after a vast research along several dealerships we manage to find the rear hub. The handlebar was also hard to acquire, as the mounting part was difficult to build. The most difficult part was to build a chain and seat stray with unit to hold the battery box under the seat and in the center of mass. We had to build the seat and chain stray according the required space for battery box. Another difficult part was to build the new seat for straight seating position. We build an entire new seat with new seat frame and attached it with the rear wheel hub. Which actually added 2 Kg extra weight more causing the rear axle heavier than the old conventional model. In the end, all the difficulties related to the building process and component adaptations were surpassed.

7.2 Component alterations/adaptations and processes used

As we have built the bi-cycle from an old model. There were some difficulties regarding component adjustment and fittings. So we have conducted some of the part alteration in size and dimension. Our main difficulty was with the battery box mounting. We had to build an entire chain and seat stray to mount the battery box in the bi-cycle and keep it center of mass for better riding control. For this purpose, we have enlarged the the chain stray (90 mm) to hold the battery box. Due to the enlargement of chain stray we changed the size of the hub and restored a new hub as it can be available as per the standard size of the market. We also cut the seat tube as for the battery box position. So we welded the cutted portion of the seat tube in diagonal position for frame rigidity with top and down tube. For the seat arrangement we removed the old seat and build a new straight seat for straight position. For that we had to mount the seat with seat tube and wheel hub. Which increased extra 2 kg of material thus entire gross weight. The handle bar has to be altered for enhancing the height as old cycle had the straight handle which will lead to riding fatigue for the rider.

7.3 Testing & Final Result

Range Testing

Figure 7.1: Concluded prototype

Figure 7.2: Handlebar assembly

Figure 7.3: Prototype in the folding position

According to our calculation we will have a range of 20 Km in one-time charge interval. We have tested the project cycle fully by electric motor in the urban area of Chittagong. We have tested the range of the bicycle from Halishahar to Bahaddarhat , distance of 12 Km .Total up and down distance than 12×2 = 24 Km. We successfully covered 25+ Km.In one charge. Using only electric motor.

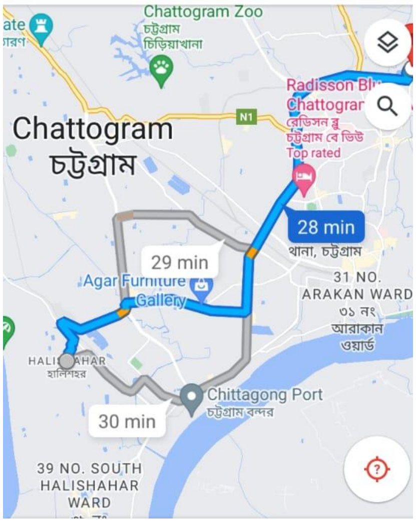


Figure 7.4 : Real life testing

Top Speed Testing

We have tested the top speed of the bicycle in a 400 m long distance of regular road and calculated the time to cover 400 m. It took 1 min to cover 400 m. And converted to Kmph and the result is 24 Km/h.

Chapter 8

Conclusions and Future work

This work was developed with the intent to project and build an electrically assisted bicycle adapted to the urban environment. It is a concept designed to create a better and versatile alternative to be used as mean of transportation in urban scenarios. It should present advantages and better features than the usual choices, as public transports, private cars or common bicycles. The project was thought to simplify and ease the transport in a in big city environments in general, yet, it was mainly aimed to be applied in the micro-mobility concept. It was made a study on the market of electrical bicycles which revealed a large and exponential growth of sales of electrical bicycles in the last years. It showed that the future will certainly include electrical bicycles, not only to be applied in urban environments but to a varied range of applications. Growing environmental concerns allied with the development of the technology were two of the main reasons that led this market to experience such a high popularity in the present. In order to achieve a product that represents a viable solution as a mean of transportation and mainly. The requirements constitute crucial characteristics and features that the bicycle should present and they were considered to be: autonomy, weight, ease on transportation, practicability and safety. Starting from these key aspects, we could then proceed to project and engineer a suitable solution. Being a bicycle, or electrical bicycle, composed by several components, all these have to be properly chosen in order for them to be in compliance with each other and create a viable and capable solution. Since bicycles are old means of transport, they've experienced a wide evolution as well as their components. Hence, there are several different options for the different components that compose a bicycle. This way we made an evaluation to the different component alternatives in order to choose systems suitable for our purposes and that could create a viable set. Due to project limitations, as referred before, we've designed an existing diamond frame model. A future work and development of this project would be the improvement and reinforcement of the design as well as considering other alternatives, possible better suited, to hold the bicycle in achieving better mileage. Regarding the raw material used, it can be analyzed different alternatives for it, with lighter and better suited materials, as carbon fiber for example. With this work it was possible to conclude that bicycles, and even more, electrically assisted bicycles, not only have played an important role as a mean of transportation but its importance tends to keep on growing, as they are continuously improving. With the technology advances and breakthroughs, electrical bicycles are a concept that is meant to grow increasingly more and tend to extend its range of applications. With this work we were also able to conclude that despite the technology surrounding the concept had seen great developments, the concept is still severely limited by it. This refers mostly to the batteries, as they constitute a crucial component, limiting the bicycle range and extending its weight (two of the requirements considered to the project). In a close future, and with the advance of technology, these major drawbacks are expected to be overcome, as batteries are in continuous update. New and more efficient motors are also starting to appear, as well as retroactive systems which allow to recharge the battery while the bicycle is being ridden.

References

[1] A. A. A. M. R.-U.-R. Afaque Umer1, "Strength and Stiffness Optimization of Diamond Frame using Corrugated Tube," *Researchgate ,* p. 11, 2018.

[2] "https://www.electricitybikes.com/blog/diamond," ElectriCity Bikes, [Online]. Available: https://www.electricitybikes.com/blog/diamond.

[3] "https://www.britannica.com/biography/Nicolas-Joseph-Cugnot," Britannica, [Online]. Available: https://www.britannica.com/biography/Nicolas-Joseph-Cugnot.

[4] "https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle," United States Environmental Protection Agency , 30 June 2022. [Online]. Available: https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle.

[5] "https://en.prothomalo.com/bangladesh/8dk4ii221f," Prothom Alo, 13 September 2022. [Online]. Available: https://en.prothomalo.com/bangladesh/8dk4ii221f.

[6] "https://www.facebook.com/marketplace/106899342673978/hybrid-bikes/," [Online]. Available: https://www.facebook.com/marketplace/106899342673978/hybrid-bikes/.

[7] 2. P. M. K. N. Mr. Mahanthesh.M.R., "Numerical Analysis for a Bicycle Frame made ofMild Steel and Composite," *IJRTI,* p. 40, 2018.

[8] "https://www.bicycling.com/bikes-gear/a21784287/bike-frame-materials-explained/," [Online]. Available: https://www.bicycling.com/bikes-gear/a21784287/bike-frame-materials-explained/.

[9] M. Ahmed, "Material, Design & Analysis of a Bicycle Frame," Academica.edu, 2014.

[10] M. Ahmed, "Material, Design & Analysis of a Bicycle Frame," Academia.edu, 2014.

[11] 1. C. I.-C. M. K. X. M. J. P. a. A. S.-B. Rubén Usamentiaga, "Nondestructive Evaluation of Carbon Fiber Bicycle Frames Using Infrared Thermography," *National Library of Medicine ,* p. 1, 2020.

[12] "https://www.worldometers.info/bicycles/," [Online]. Available: https://www.worldometers.info/bicycles/.

[13] "https://pedegoelectricbikes.ca/electric-bike-pedal-assist/#:~:text=Electric%20bikes%20typically%20offer%20two,you%20are%20pedalling%20or%20not.," 17 July 2021. [Online]. Available: https://pedegoelectricbikes.ca/electric-bike-pedal-assist/#:~:text=Electric%20bikes%20typically%20offer%20two,you%20are%20pedalling%20or%20not..

[14] "Projected global sales of electric bicycles. http://www.statista.com/statistics/255658/," [Online]. Available: Projected global sales of electric bicycles. http://www.statista.com/statistics/255658/.

[15] "The global e-bike market. http://www.insg.org/%5Cdocs%5CINSG_Insight_23_Global_Ebike_," [Online]. Available: The global e-bike market. http://www.insg.org/%5Cdocs%5CINSG_Insight_23_Global_Ebike_.

[16] "C. of the European Market Industry. European bicycle market, 2015. Industry and Market profile," [Online]. Available: C. of the European Market Industry. European bicycle market, 2015. Industry and Market profile.

[17] "C. of the European Market Industry. European bicycle market, 2015. Industry and Market profile," [Online]. Available: C. of the European Market Industry. European bicycle market, 2015. Industry and Market profile.

[18] [Online].

[19] "https://www.pranshu.com/2022/02/23/what-is-pmdc-motor-and-how-it-works/," [Online]. Available: https://www.pranshu.com/2022/02/23/what-is-pmdc-motor-and-how-it-works/.

[20] "https://www.pranshu.com/2022/02/23/what-is-pmdc-motor-and-how-it-works/," [Online]. Available: https://www.pranshu.com/2022/02/23/what-is-pmdc-motor-and-how-it-works/.

[21] "https://www.uumotor.com/faq/10-advantages-and-disadvantages-of-hub-motor.html," [Online]. Available: https://www.uumotor.com/faq/10-advantages-and-disadvantages-of-hub-motor.html.

[22] "https://www.uumotor.com/faq/10-advantages-and-disadvantages-of-hub-motor.html," [Online].

Available: https://www.uumotor.com/faq/10-advantages-and-disadvantages-of-hub-motor.html.
[23] "http://www.ebikeschool.com/," [Online]. Available: http://www.ebikeschool.com/.
[24] "https://en.wikipedia.org/wiki/Cadence_(cycling)," [Online]. Available: https://en.wikipedia.org/wiki/Cadence_(cycling).
[25] "https://en.wikipedia.org/wiki/Pedelec," [Online]. Available: https://en.wikipedia.org/wiki/Pedelec.
[26] "https://esmart.com.bd/product/venture-electric-mountain-bicycle-unicorn/," [Online]. Available: https://esmart.com.bd/product/venture-electric-mountain-bicycle-unicorn/.
[27] "https://esmart.com.bd/product/venture-electric-city-bicycle-3/," [Online]. Available: https://esmart.com.bd/product/venture-electric-city-bicycle-3/.

Appendix

Figure A.1: Welding the customized seat

Figure A.2: Welding the customized seat

Figure A.3: Making the seat stand

Figure A.4: Installing the seat with the new frame

Figure A.5: Old Bi-cycle