Analysis on Effect of Wheel Size in PEV Performance

by

Syamilah binti Yaakub
17336

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons) Mechanical

January 2015

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan.

ABSTRACT

The emergence of personal electric vehicle (PEV) in the market place shows huge evolution on the conventional vehicle. The famous PEV in the market nowadays is SEGWAY personal transporter, the price is cheaper than another design made by Toyota, iRoad. This is shows many car manufacturers drastically invested on the research of PEV to expand its potential. The PEV is safe to the environment as its using electricity energy to move and battery to in store the energy. However, the existing PEV still have limitation on the design based on the wheels size and more specifically, the main question addressed what is the torque requirement for the PEV to achieved. Thus, this paper will addressing regarding the wheel technology since wheel id determined to contribute important implication to the movement of PEV, the power requirement and the total torque in different wheel size. to execute the analysis on the parameter setup, the research has been done based on PEV journal and previous research. In addition, the objective of this project is to analyse the effect of wheel size in PEV performance.

ACKNOWLEGEMENT

The completion of Final Year Project will not be a success without the help and guidance from my supervisor and colleagues. Hereby, I would like to express my heartfelt gratitude to those I honour.

First of all, I would like to give appreciation to my direct supervisor, Mr Azman Zainuddin, lecturer of Mechanical Engineering Department, Universiti Teknologi PETRONAS. Thanks to his valuable supervision, guidance and support throughout my project, I able to complete the project successfully. Apart from this, a million thanks to Mr Kamal Ariff Zainal Abidin, who also evaluated, guided me and given beneficial suggestion to me for improvement. I also wish to express my gratitude to my fellow teammates and colleagues, who were always so cooperative and always there to provide suggestions and comments on each my works for further improvement.

Lastly, I would like to thank my parents and my family members for their support during our final year study. With their support, I managed to perform well and persevered through any obstacles faced during the project.

Table of Contents

List of Figure

List of Table

CHAPTER 1

INTRODUCTION

1.1 Background

In this era of globalization, there are three main source of energy are fossil fuels, natural gas, and coals. However, the usage of these sources of energy led to another problem of global warming issues and the depletion of the sources. Hence, to reduce the dependency on these sources, this issue must be tackle by introducing the usage of renewable energy in order to stabilize the climate. One of the best way to do so is increasing the transportation efficiency which can help reducing the emission of carbon dioxide (CO_2); primary culprit in global warming. Based on (Livesmartbc.ca) transportation contributed 36% of greenhouse emission. Personal electric vehicle (PEV) is the new category of transportation which was first introduced in late 1990s. By definition, based on (Afdc.energy.gov, 2015) PEV is a vehicle that draws electricity from a battery with a capacity of at least 4kWh and is capable of being charged from an external source where the vehicle have gross weight of less than 8500 pounds with a maximum speed of at least 65 miles per hour or 27 meter per second.

In addition, since the main source of energy for PEV is electricity, it is expected that this vehicle can meet the zero emission where it does not emit emission while driving. Moreover, electric trikes and tricycles, also known as adult three-wheelers is one of the PEV types where this type of vehicle does not require balancing like 2-wheeled bicycle and was normally used for short trips distances ranging from 1-10 km. Compared to normal 2-wheeler mode of transportation, tricycle is more balance and more friendly user especially to those who never learned to balance a 2-wheeler (Electric-bikes.com, 2015).

The vehicle can be separated into three basic functions of energy storage, drive system, and chassis. The chassis consist of the rider interface such as wheels, braking, system, and the structure that are able to support and locates all of the other elements of the vehicle (Ulrich, 2005). Thus, this paper will provide an overview of the wheel technology that is more suitable to be used for tricycle type of PEV.

1.2 Problem Statement

Global warming nowadays is one of the major problems that can harmful to mankind and wildlife. This problem is getting worse from day to day. If the situation worsen continuously, at the end of this century the earth temperature will rise to highest over the past 2 million years. There are stack up of reason to cause global warming and one of it is carbon dioxide void by vehicle itself. So the environment-friendly petrol private will be main trend of the society.

Since the oil price very expensive, the daily usages of passenger vehicle need to be controlled. Instead, most of the usage believe that electricity vehicle do not decrease people's drive passion because they said electricity vehicle is not powerful and limited usage per time as petrol car such as the speed and the control.

Moreover, most of the transportation sector now is powered by fuels that derived by oil. To reduce the dependency on oil usage and the costing price, alternatively electric power vehicle and hybrid system vehicle can overcome this problem. Electric driving is considered as alternative way to produce zero pollution and does not produce pollute the atmosphere in the environment compare to internal combustion engine (ICE). It could neutralize the environment when the usage of this type of vehicle increased. In addition, electric vehicle is a green technology that should adapt in all country, general speaking in the world today whereas in this moment world have many pollution from many sources.

Bicycle or motorcycle can be seen as alternatives way for personal urban mobility usage, since they enable people to travel longer, faster, with less effort rather than walking and low environment impact. Thus, in this report we focused on electric scooter because it's small size, cheaper, less noisy and zero pollute environment.

Nowadays, small scooter or personal electric vehicle (PEV) becomes popular especially during recreation time, relaxing and for human exercise after they had faced their job. There is a lot of PEV type around us like stand on scooter, sit on scooter and mobility scooter. Most of that is operation by motor electric or just using our leg to move scooter like playing skate board.

The problem is, most of the technology in PEV got limitation on the design based on the wheel size. And more specifically, the main questions addressed can be how light PEVs be, how far they can go, how much is the cost at the efficient frontier. This will be discussed further inside this report.

1.3 Objectives

The objective of this study can be described as the following:

- To perform dynamic analysis of a PEV for a given set of requirement.
- To study the influence of wheel size on power requirement

1.4 Scope of Study

In this report, the author will deeply discuss on the analysis of the wheel for personal electric vehicle (PEV). The requirements based on the design set by F. Zainor (2011) are:

Table 1.2 Requirement based on F.Zainor (2011)

Requirement	Feature
Type of PEV	Three –wheeler scooter
Type of tire	Pneumatic tire
Mass (PEV+Rider)	15kg + 70kg
Wheels radius	0.1m, 0.175m and 0.25m
Speed	0 – 20km/h in 10 second
Type of terrain on asphalt concrete * (coefficient of friction)	Dry road = 0.8 Wet road = 0.4

*value of coefficient of friction will be based on the www.engineershandbook.com as in appendix

The author narrows the analysis by using pneumatic type tire because most of the electric scooter used this type of tire to absorb shock loads from impacts. In the other hand, the authors will focused on the rolling resistance of the vehicle and the torque.

CHAPTER 2
LITERATURE REVIEW

2.1 Personal Electric Vehicle (PEV)

By definition, personal electric vehicle (PEV) can be defined as any motor vehicle that can be recharged from an external source of electricity, such as wall sockets, and the electricity stored in rechargeable battery packs drives or contributes to drive the wheels. PEVs transport a single passenger over a long distance trip ranging from 1-10km and typically open to the weather and have a maximum speed of 100 km per hour (Electric-bikes.com, 2015). There are several types of PEV such as electric scooters, electric bicycles and also electric motor-scooters and motorcycles. The difference type of PEVs and the speed range are as shown in table 2.1 below.

Table 3.1 Different types of PEVs and typical speed range (Electric-bikes.com, 2015)

TYPE	RANGE OF SPEED (km/h)
Electric Scooters	16 – 24
Electric Bicycles	19 – 32
Electric Tricycles	16
Electric motor scooters and motorcycles	32 – 72
Commute Cars	64 – 112
Power-Assist wheelchair	11
Electric Go-Karts	8 – 40

For this project, the author will be focusing more on electric motor scooters with the speed ranging from 20 mph to 45 mph. Performance of electric motor-scooters lies between electric bikes and gas-powered motor-scooters. Due to range limitation, electric motor-scooters are city cycles, not touring but able to offer better acceleration and less maintenance required compared to fossil-fuelled bikes. For the better performances in term of balancing, electric trikes or three-wheelers transportation can provide better as it does not require balancing.

Three-wheel scooter is found to be more user-friendly especially to the user who never learned to balance 2-wheeler transportation as shown in figure 2.1 below.

Figure 2.1: Electric motor-scooters (Electric-bikes.com, 2015)

There is few benefit of using electrical vehicles which are as listed below: (Electric-bikes.com, 2015) (Tomwoodthink.com, 2015)

- ✓ Reducing global emission

  Well-to-wheel analysis reveals that electrical engines, due to their winning energy efficiency, are significantly cleaner than any other personal transport alternative today.
- ✓ Energy efficient

  Electric vehicle converted about 59%-62% of the electrical energy from the grid to power at the wheels whereas conventional gasoline vehicles only convert about 17%-21% of the energy stored in gasoline to power at the wheels. This happened since most of the energy provided by the gasoline, or bio fuels disappear as heat.
- ✓ Performance benefits

  Electric motors vehicle provide quiet, smooth operation and stronger acceleration and require less maintenance.
- ✓ Reduce energy dependences

  Because the main source of energy for the vehicle is electricity, the dependency towards the fossil fuels is close to none.
- ✓ Sustainable future

The market for green energy is growing rapidly; the government all across the world are improving the regulatory framework for expanding the renewable energy production. In many countries nowadays, the guaranteed pure, renewable energy can be purchase which will help reduces the vehicle emissions to zero.

2.2 Typical architecture of PEV

2.2.1 Comparison and differences of electric vehicle and fuel vehicle

The electric vehicles (EVs) system is a system of high complexity comprised of technical and non-technical compositions. They are known for their low maintenance cost, absence of pollution, quite engine etc. In spite of all the advantages they claim, they have not become popular yet.

The differences between electric scooter and the normal scooter are environmental impact, the electric scooter is to help save the planet by reducing harmful emission (Geiser Aaron, 2009). All EVs do not release toxic emission such as nitrogen, carbon dioxide, unlike their counterparts, have a miniscule carbon footprint, are much better for the environment. The normal scooter or gasoline-used scooter burn fuel which gives off emission those are harmful to our environment, their toxic output from the exhaust can be very high because gas scooter are not held to the same emissions standards as regular cars. Moreover, gas scooter produce louder sound because the combustion of the gas inside the engine take place (WordPress, 2015). The noise level of gas scooter can be compared to a motorcycle, lawnmower or leaf blower. An EV is very quiet and usually gives off a low humming sound rather than the high volume sound produced by gas scooter (Geiser Aaron, 2009). On the other hand, an EV can save money even though the early investment to buy this scooter a bit expensive but it can save money in long term. The high priced petrol nowadays that always fluctuate and limited fuel can be avoided (WordPress, 2015). In figure 2.2 and figure 2.3 below shown the example of EV and the normal scooter and as shown in figure 2.4 and 2.5 the example of electric car and internal combustion engine.

Figure 2.2: 3 wheeler electric scooter (Blueplanetgreenliving, 2015)

Figure 2.3: Gasoline scooter (Blueplanetgreenliving, 2015)

Figure 2.4: normal internal combustion engine

Figure 2.5: Electric vehicle by Tesla Motor

2.3 Energy Storage

System for PEVs is comprised of three basic functions of energy storage, drive system and the chassis (Ulrich, 2005). This can be showed as figure 2.6 below.

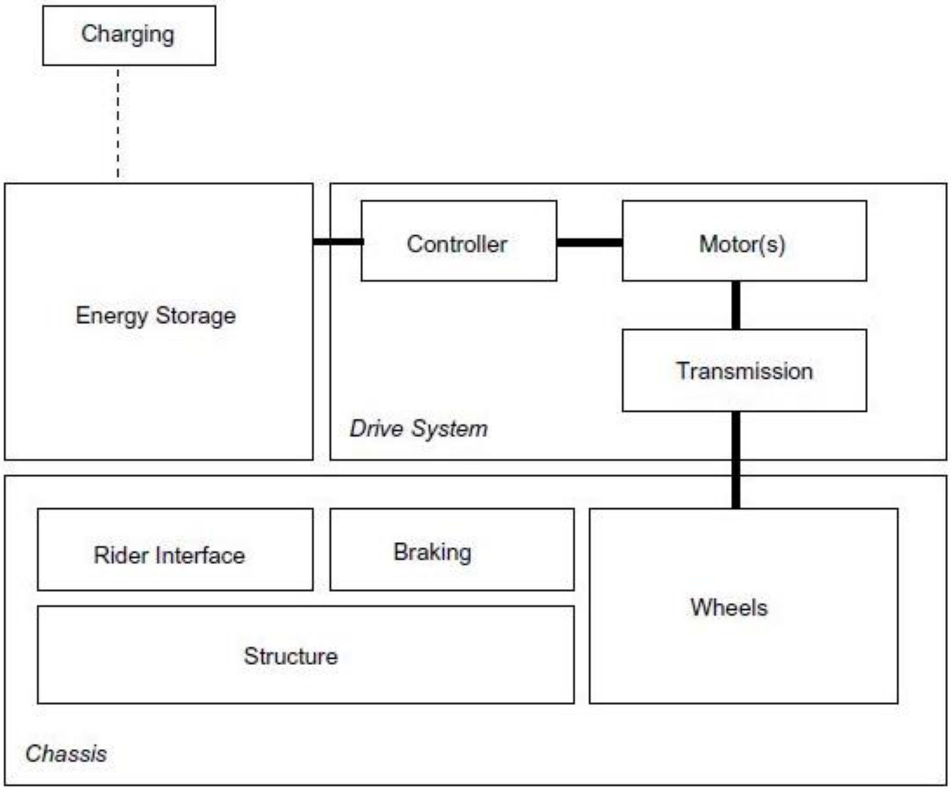

Figure 2.6: System architecture for personal electric vehicle (Ulrich, 2005)

The supporting function for PEVs from the figure above shown is charging. The charging process can be accomplished by an on-board or off-board device (Ulrich, 2005). Furthermore, for battery powered vehicles is typically connected to a standard electrical outlet when charging the vehicle batteries. In energy storage technology of EVs can be distinguished in three types (van Essen & Kaupman, 2011) (Wakefield, 1998) :

- Full electric vehicle that have an electric engine and batteries for energy storage, no internal combustion engine (ICE).

- Plug-in hybrid electric vehicle (PHEVs) that have both an ICE and electric engine with a battery that can be charge on the grid.
- Electric vehicles with a range extender (EREVs) that have an electric engine and an ICE that can be used to charge the battery and so extend the vehicle's range, the battery of an EREV can be charged on the grid.

The last two points above, PHEVs and EREVs are not commercially viable for PEV at this time. Therefore, batteries of various types are the principle means of energy storage available to the PEV designer.

2.3.1 Sealed Lead Acid Battery (SLA)

Most EVs especially electric scooter application is used sealed lead acid (SLA) battery types (Ulrich, 2005) (Nycewheels.com). These batteries have been widely used in forklift, golf carts, electric wheelchairs, back-up power supplies for alarm and other smaller computer system called UPS. While electric bikes which normally require human input by pedalling have opted for newer technologies of batteries to keep the bike light as possible. This is largely due to the fact that SLA are heavy compare to nickel metal hydride and lithium ion batteries (Ulrich, 2005). The advantages of SLA is they cheaper and reliable (Nycewheels.com). Figure 2.7 shown various sizes of SLA batteries.

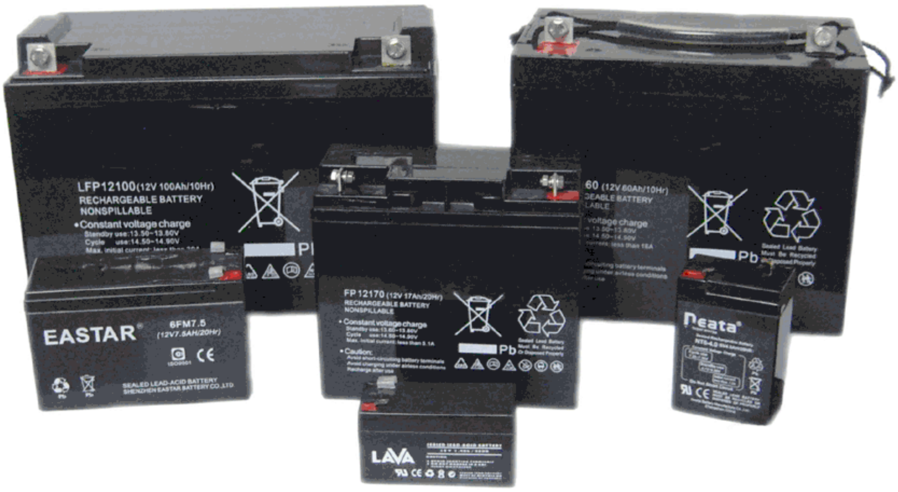

Figure 2.7: SLA batteries in various sizes (Safeguardquotes.info, 2015)

2.3.2 Nickel Metal Hydride (NiMH)

Nickel metal hydride or NiMH batteries significantly lighter than SLA batteries but there is a jump in the price. A NiMH batteries need to be recharged about once a month if not in use to maintain full capacity, which result more costly electronics for supporting the batteries (Ulrich, 2005). Nevertheless, NiMH have a better overall lifetime and battery will last about 500 full charge cycles before it needs to be replaced (Urban Transportation, 2014). Normally, NiMH battery used in cordless power tools and many portable computers example in figure 2.8 below.

Figure 2.8: Nickel metal hydride (NiMH) battery (Nycewheels.com)

2.2.3 Lithium Ion Battery (Li-Ion)

The newest technology in batteries is lithium ion batteries (Li-ion). They widely used in mobile electronic device or laptop batteries because of a little bit lighter and battery will last about 800 full charge cycles before it needs to be replaced (Urban Transportation, 2014). In one of the famous PEV, Yamaha Passol in figure 2.10, they used this type of batteries. Lithium batteries also feature the benefit of being largely maintenance free. The cost of Li-ion cost more than NiMH batteries, but the cost per mile ends up being roughly the same (Ulrich, 2005). Figure 2.9 shown above is inside lithium ion battery.

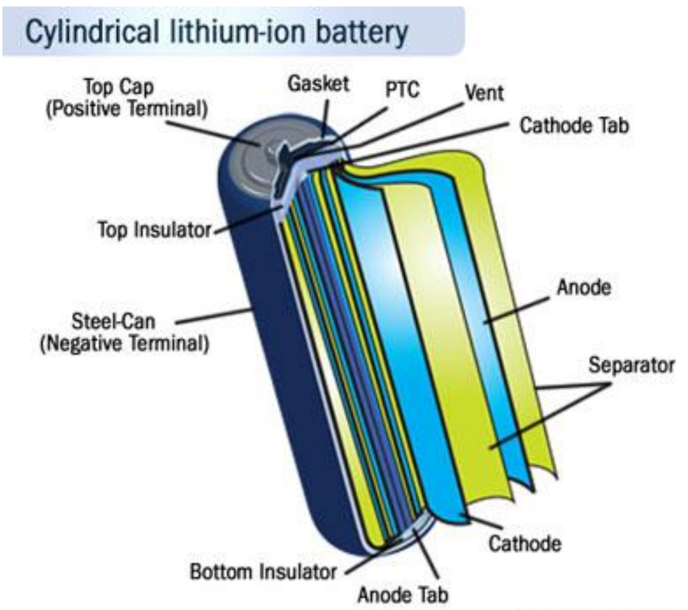

Figure 2.9: Inside the lithium ion battery (Marshall Brain, 2010)

Figure 2.10: Yamaha Passol (Electric Vehicle)

In PEV, three categories of energy storage technologies have been discussed above with the example used in commercial electric vehicle. In table 2.2 below shown the summary properties of three battery technologies for personal transportation application.

Table 2.2: Summary of three battery technologies for PEV application (Ulrich, 2005)

		Sealed lead acid	Nickel metal hydride	Lithium ion
Energy density @ 1C discharge rate	kJ/kg	87	207	448
Power density (continuous)	W/kg	200	200	500
Cost per unit mass	US$/kg	2.50	30.00	90.00
Cost per unit energy	US$/MJ	29	145	201
Number of charge–discharge cycles possible (until only 80 percent of original capacity is available)	Cycles	150–200	200–400	500+
Maturity of technology	Years use in transportation applications	≈80	5	2

2.4 Drive system

An electric drive system replace the internal combustion engine and assorted transmission systems with an electric system. Drive system of EVs consist of the system; motor, controller and transmission and power source; batteries (Lin, 2014). As conclusion, the drive system is comprised in turn of one or more motors coupled through a mechanical transmission to the wheels. In all cases, the power from the energy storage part is modulated through some kind of controller, implemented as an electric device. The various differences of electric drive system are listed table 2.3 below:

Table 2.3 : Comparison of power system (Lin, 2014) (Ulrich, 2005)

Internal combustion system	**Electric battery system**	**Electric fuel cell system**
• Engine including cylinder, air intake, fuel tank, carburettor and air filter • Pump for lubricating oil and oil tank • Exhaust system • Transmission and chain • Starter battery	• Battery • Electric motor(s) • Motor controller • Transmission and chain	• Fuel cell stack • Fuel cell subsystem including cooling system, air intake, hydrogen intake, humidification system if any • Hydrogen storage device • Electric motor(s) • Motor controller • Transmission and chain • Battery for start-up

2.4.1 Electric motor technology

Electrical motors operate on the basic principle that a current-carrying wire in a magnetic field will experience a force. The magnetic field can be generated by permanent magnets or by a current in an electromagnet (Ulrich, 2005). The stator is stationary and produces the magnetic flux, while the rotating armature or rotor contains the coils that carry the armature current (Lin, 2014). Generally, motor speed is controlled by increasing the armature voltage, while torque is controlled by increasing the current flowing through the armature shown in figure 2.11 below.

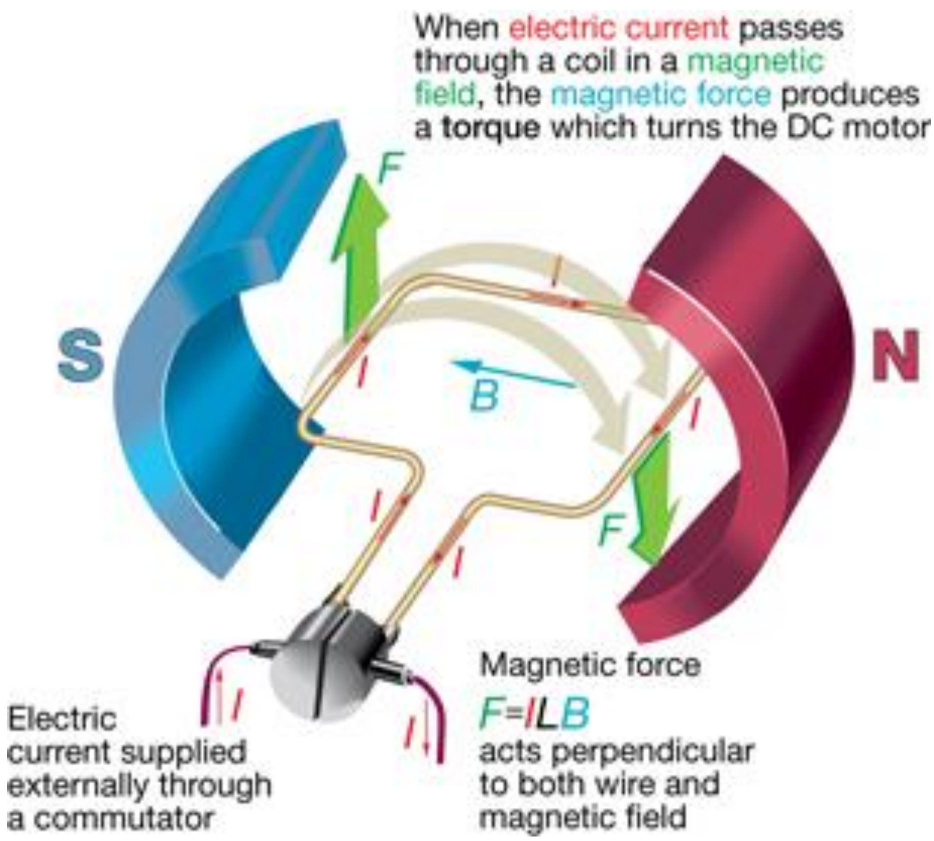

Figure 2.11: Direct current electric motor (Rockyview, 2013)

Differ from combustion engine, the explosion of air or fuel mix directly produces rotation with a fixed velocity-torque relation. More flexibility can be achieved in an electric motor, where the ratio between torque and speed can be controlled independently and electronically within the motor or controller (Lin, 2014). Transmissions are often not being necessary at all; where used, they offer optimum efficiency for both driving and regenerative braking. The central technology choice for drive system is between brushless DC motor and brushed DC motor (Ulrich, 2005).

a) DC Motors

DC motor or direct current motors employ a fixed current that cause the rotor turn to line up with the poles in the stator. However, the current in the stator is commutated, often by a split-ring brush system, so that the direction of the current in the poles switches as the rotor passes by (Lin, 2014). This ensures that the rotor stays in continual motion. General speaking, controllers are cheaper than for AC motors, on the other hand the motors themselves tend to be bulkier and heavier and more expensive (Larminie & Lowry, 2004).

In the basic brushless motors, the windings or called the coils of copper wire are in the stator and the rotor that is a permanent magnet (Ulrich, 2005). With this kind of instrumentation, it gives better cooling and higher power levels compare with other arrangement in which the windings are on the rotor and the magnets on the stator (Lin, 2014). For brushes DC motors, high levels of current result in substantial inefficiencies due to resistive losses in the brushes (Ulrich, 2005). This happen because of the cooling limitation, brushed motors are most efficient when run at relatively high speeds (5000-20000 rpm) and low torque. The arrangement of brushed DC motor and brushless DC motor as shown in figure 2.12 below.

On the other hand, brushless motors can operate efficiently at high torque and the speeds as low as 1000 rpm. This difference in minimum efficient speeds leads to a substantial difference in transmission requirements (Ulrich, 2005). In conclusion motor torque is proportional to motor current (Lin, 2014).

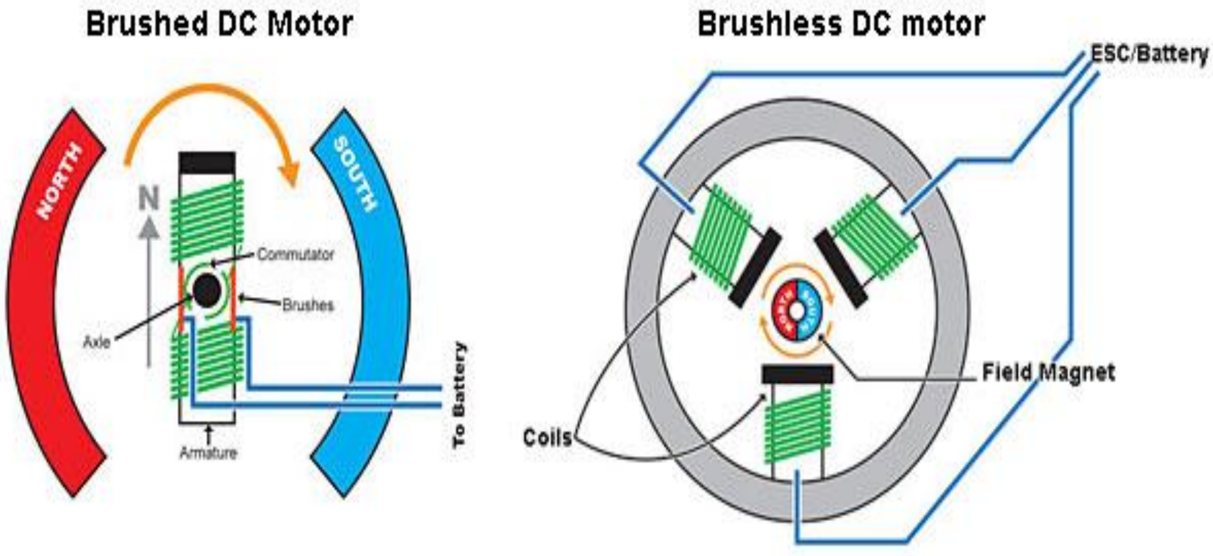

Figure 2.12: Brushed and brushless DC motor (RC Think, 2004)

2.5 Wheel technology

The power and energy required at the wheels are determined by the basic physics of moving a wheeled vehicle over the road surface through the air. The power acting at the wheels can be modelled as the sum of power required to overcome air drag, the power associated with the climbing or descending a slope, the power related with accelerating or decelerating the vehicle and power required overcoming rolling resistance (Ulrich, 2005).

$$\boldsymbol{P} = \boldsymbol{P}_{\textit{Rolling}} + \boldsymbol{P}_{\textit{Air-Drag}} + \boldsymbol{P}_{\textit{Slope}} + \boldsymbol{P}_{\textit{Acceleration}} \qquad (1)$$

Movement behaviour of vehicle along its moving direction is completely determined by all the forces acting on its direction which can be seen in figure 2.13. The tractive effort, F_t in the contact area between the tires of the driven wheels and the road surface will make the vehicle moving forward (Ehsani, Gao, & Emadi, 2009). While the vehicle is moving, there have some resistance that tries to stop its movement which is rolling resistance, aerodynamic drag and uphill resistance.

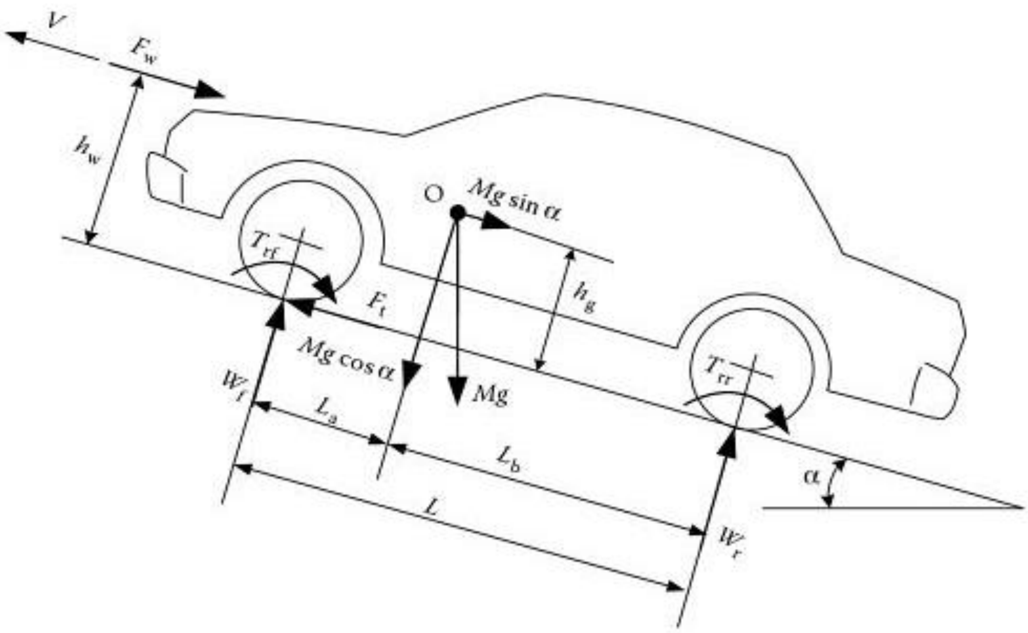

Figure 2.13: Forces acting on a vehicle moving uphill (Ehsani et al., 2009)

2.5.1 Rolling Resistance

Where does rolling resistance come from? The answer is rolling resistance is mainly due to visco-elastic properties of the rubber compound used to make tires (Barrand & Bokar, 2009). When the tire being deformed, this type of material dissipates energy in the form of heat. Figure 2.14 shown below all the forces acting on a vehicle along a slope.

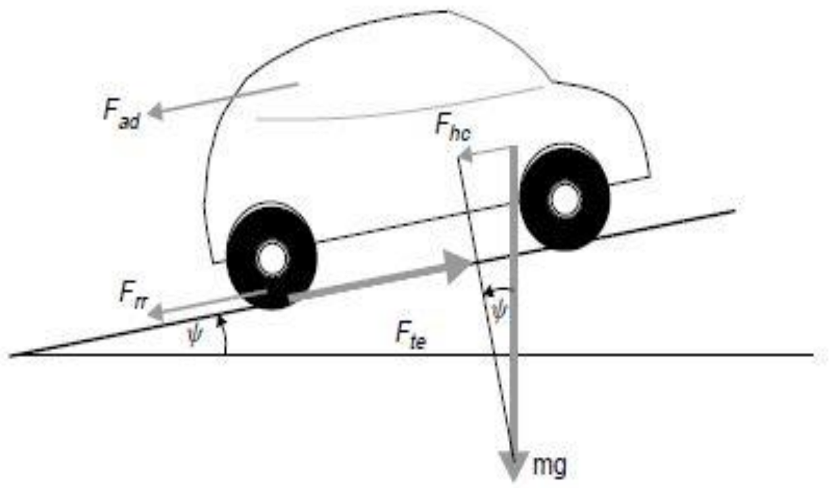

Figure 2.14: The forces acting on a vehicle moving along a slope (Larminie & Lowry, 2004)

The rolling resistance of a vehicle is usually taken to be the sum of all the forces acting through the wheels and axles that oppose its motion (Patch, 2012). Nevertheless, the rolling resistance accounts for a significance proportion of the total fuel consumed by the vehicle and worthwhile reductions are still possible. Most of the processes that contribute to rolling resistance are steady-state processes that drain energy at a constant rate while the vehicle is moving at constant speed.

The rolling resistance of tires on hard surface is primarily caused by hysteresis in the tire materials. Hysteresis is the phenomenon when a visco-elestic material like rubber has been deformed, it reverts to its initial shape only after a certain time, not always perceptible to an observer (Barrand & Bokar, 2009).

There have so many material of tire in the market nowadays, such as urethane-tired and pneumatic-tired (Ulrich, 2005), which can be explained later. The force of the rolling resistance is function of the weight of the vehicle multiplied by a coefficient of rolling resistance (Kim, Lee, & Shin, 2013).

$$\boldsymbol{F_{rr} = mg\,Cr} \qquad (2)$$

Where: m = mass of rider and vehicle (kg)

g = gravitational constant ($9.81m^2/s$)

C_r = coefficient of rolling resistance

Typical values of rolling resistance coefficient on various roads are given in the table 2. The rolling resistance force is the relationship between the tires and the road (Szadkowski, Chrzan, & Roye). Power require to overcome rolling resistance can be expressed by,

$$\boldsymbol{P_{rolling} = mg\,C_r V} \qquad (3)$$

Where: m = mass of rider and vehicle (kg)

g = gravitational constant ($9.81m^2/s$)

v = velocity of the vehicle (m/s)

C_r = coefficient of rolling resistance

On the flat surface at constant velocity, there have two important principle components of power: rolling resistance and air drag (Ulrich, 2005). At low speed, rolling resistance dominates the power requirement and at high speeds air drag dominates (Szadkowski et al.).

From the moving wheeled vehicle over the road surface and through the air it can be determine the power and energy required (Ulrich, 2005). In terms of electric vehicle, the energy that must be stored in the vehicle is greater than that required at the road surface, with the difference accounted for by losses in the control electronics, motor and mechanical transmission.

Table 4.4: Rolling resistance coefficient (Ehsani et al., 2009)

Rolling Resistance Coefficients

Conditions	Rolling Resistance Coefficient
Car tires on a concrete or asphalt road	0.013
Car tires on a rolled gravel road	0.02
Tar macadam road	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tire on a concrete or asphalt road	0.006–0.01
Wheel on iron rail	0.001–0.002

a) Inertia

Inertial forces are very significant on trips involving many stops and starts such as traffic light, stop signs and road junction. For example, stop and go trips are usually in towns, when crossing built-up areas or on winding roads. Speed is usually more constant on trips when higher average speed can be maintained such as motorway driving.

Inertial forces are directly proportional to the vehicle's mass. The heavier the vehicle, the greater its inertia. An object does not only have inertia when braking or accelerating during translation. It also has inertia during rotation (Barrand & Bokar, 2009). For example, if a brick placed on a table. A string is attached to pull it across the table. If the string is pulled gently, the brick will move, but if it is pulled abruptly it may break. In another example, if we want to slow or stop a moving object assume the car is cruising at 3 to 4 km/h with the engine off. If someone suddenly standing in front of it, the person will get pushed over by the vehicle's momentum. However, if the person standing on the side of the vehicle and gradually slow it down while moving along with the vehicle for a few steps, then the person manages to stop it, this can be seen in figure 2.15 shown below. In conclusion, a moving object seeks to continue along its path and resist efforts made to stop it (Nave, 2010).

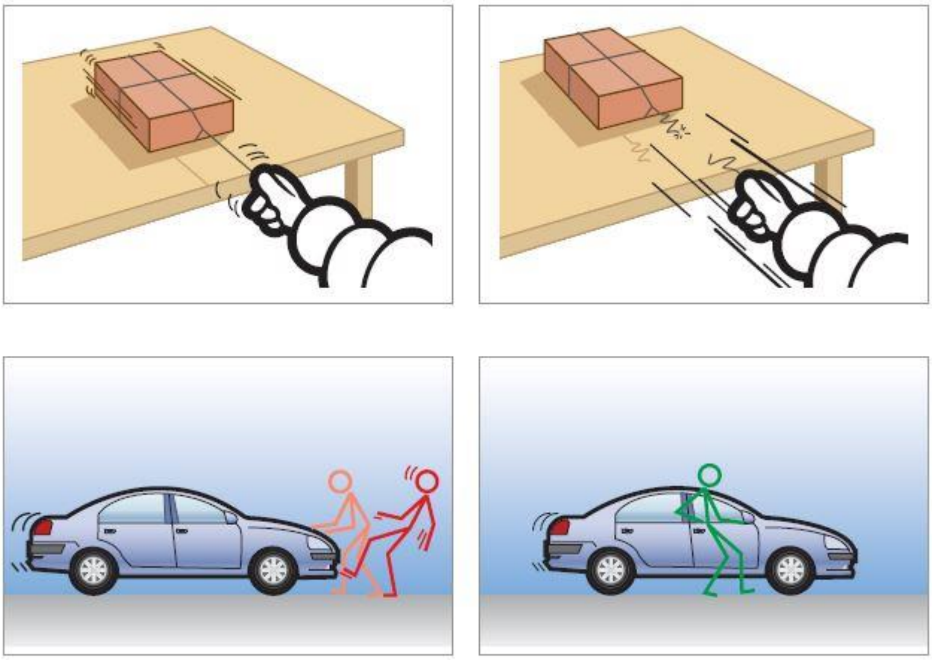

Figure 2.15: Example of inertia forces (Barrand & Bokar, 2009)

In rotational inertia, we need to consider all rotating parts in a vehicle. The rotational inertia of a passenger car is estimated at 4% of the vehicle's mass which is three quarter of this amount being attributed to the tyre-wheels assemblies (Barrand & Bokar, 2009). Inertia forces subject to translation are given by:

$$\boldsymbol{F}_{inertia} = \boldsymbol{M}_{eq} \times \boldsymbol{a} \qquad (4)$$

Where: M_{eq} = vehicle's equivalent mass (kg)

a = acceleration or deceleration of the vehicle (m/s^2)

For inertia forces subject to rotation, we assume the tire same like ring which is have hollow in the middle. The rotational inertia or moment of inertia is

$$\boldsymbol{I} = \boldsymbol{mr^2} \qquad (5)$$

$$\boldsymbol{F}_{rotational\text{-}inertia} = \frac{\boldsymbol{I\alpha}}{\boldsymbol{r}} \qquad (6)$$

Where:

m = vehicle's equivalent mass (kg)

α = angular acceleration (rad/s^2)

r = rolling radius (m)

2.5.2 Aerodynamic Drag

To maximise the fuel efficiency of any vehicle the mass, aerodynamic drag and rolling resistance have to be minimised (Larminie & Lowry, 2004). A force resisting its motion when a vehicle traveling at certain speed is called aerodynamic drag (Ehsani et al., 2009). When a vehicle moving it will hit the ‘wall’ that pushes against a vehicle at high speeds. This wall we called as air resistance or the air drag which all vehicles are designed to move through it and have been for a long time. At high speeds and windy days, this air resistance has a tremendous effect on the way a vehicle accelerates, handles and achieves fuel mileage (Patrick George, 2002).

Most important component that related to aerodynamic drag is the vehicle shape drag and the skin friction. Essentially, having a vehicle designed with airflow in mind means it has less difficulty accelerating and can achieve better fuel economy numbers because the engine can work like normal operation.

Shape drag is the forward motion of the vehicle pushes the air in front of it, however the air cannot instantaneously move out of the way and its pressure is thus increase, resulting in high pressure and at the back is vice versa (Ehsani et al., 2009). This phenomenon creates a zone of low air pressure. The motion high pressure in front is pushing the vehicle forward and low pressure at the back s pulling it backwards. This can be seen in figure 2.16 shown above.

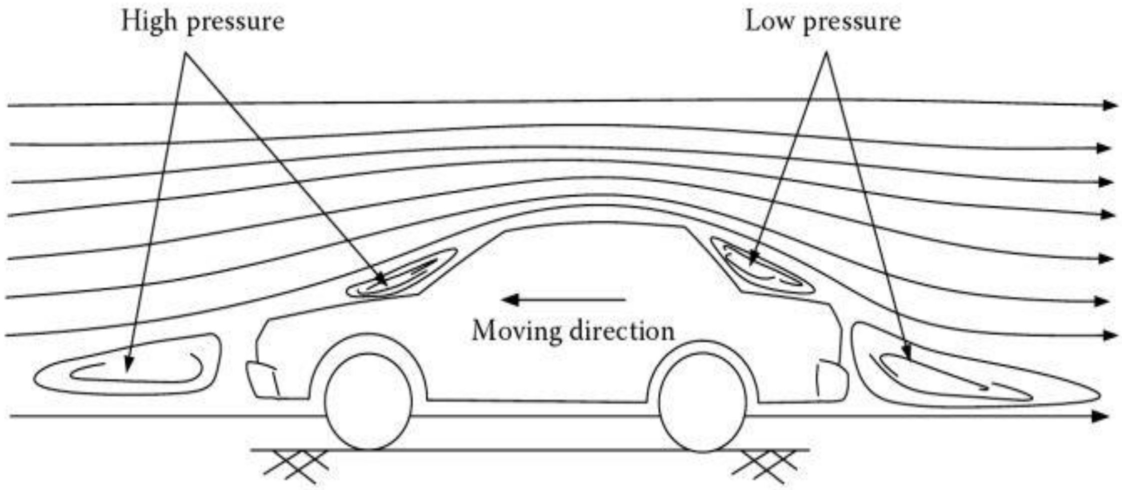

Figure 2.16: Shape drag (Ehsani et al., 2009)

Skin friction is the air close to the exterior shape or the skin of the vehicle (Ehsani et al., 2009). Automotive engineers have develop several innovation that make cutting of air easier and less impact on daily driving (Patrick George, 2002). For example, in the market nowadays more rounded designs and shapes on the exterior of the vehicle to channel air in a way so that it flows around the car with the least resistance possible. As stated in Electric Vehicle Technology book, the ideal aerodynamic shape is teardrop, as achieved by a droplet of water freefalling in the atmosphere as shown figure 2.17 below.

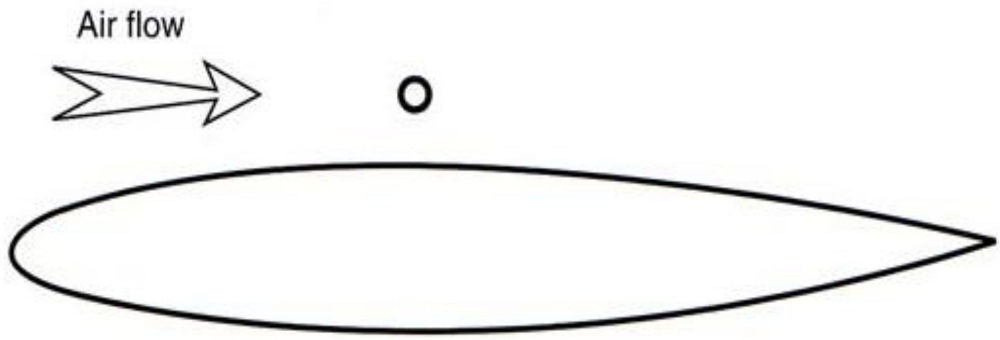

Figure 2.17: 'Teardrop' shapes (Larminie & Lowry, 2004)

Aerodynamic drag is a function of vehicle speed V, vehicle frontal area A, shape of the vehicle body and air density ρ or can be expressed in

$$F_{ad} = \frac{1}{2}\rho A C_d V^2 \quad (5)$$

Where: ρ = air density (kg m^{-3})

A = frontal area (m^2)

V = velocity (ms^{-1})

C_d= drag coefficient (dimensionless)

2.5.3 Tire Properties

Pneumatic tire type are used on vehicle as diverse in form and function as airplanes, bicycle, motorbike, tractors and race cars (Study, 2006). In other words, pneumatic tire is made of an air tight inner core filled with pressurize air as shown in figure 2.19 and a tread usually reinforced with steel belting, covers this inner core and provides the contact area with the road (Ed Grabianowski, 2007).

Smaller scooter wheels width is generally between 3 inch to 3.5 inch. The wide tires roll better than narrow because of the tire deflection (Dregni & Martin, 2006). Each tire is flattened a little under load

Pneumatic tires offers many advantages related to the highly compliant nature of rubber. The rubber tire interacts with the hard road surface by deforming under load, thereby generating the forces responsible for traction, cornering, acceleration and braking. This deformation when the wheels rolls will cause in energy losses (Ulrich, 2005). These losses are roughly inversely proportional to wheel diameter for given wheel and road materials, so larger wheels have less rolling resistance or energy losses.

Urethane tire driven without air and it is totally rubber as shown in figure 2.18. Normally for urethane tires commonly used for wheelchair, forklift, aperture tires used in the construction and material handling industry.

Figure 2.18: Wheel with solid tire or polyurethane tire ("Wheel with solid tire / aluminium / polyurethane-coated / rims ", 2010)

Figure 2.19: Allow wheel with pneumatic tire (Ed Grabianowski, 2007)

2.6 Existing Technology

Nowadays, the term personal electric vehicle or battery powered vehicle can be expressed in many types of vehicle which can be used in large variety of settings. Electric powered vehicles can be used on both public roads and private areas such as vehicles for industries, public sector, private sector, agriculture and as well as tourism sector. As the pollution is getting worsen day by day and traffic restricted zones become ever more popular in our country, only the use of electric vehicle can helps to decrease the greenhouse gasses effect ("Electric powered vehicles," 2011).

2.6.1 iRoad Toyota

Concept of this electric vehicle is all electric three wheeled trike. Invented by Toyota Corporation named i-Road, it is two-seater cabin, front and back seats which offers the same low running cost, easy to park and perfect vehicle for city streets because its fully enclosed interior makes it safer to drive as in figure 2.20 below shown (Carter, 2014).

The iRoad concept uses lithium-ion battery to power two 2kW motors mounted in the front wheels. No special skills are needed to drive the iRoad because it have special system called Active Lean which offers unique driving experience riding two-wheeler without stabilize the vehicle when cruising in low speed or stationary (Carter, 2014).

Figure 2.20: Toyota iRoad concept vehicle (Carter, 2014)

2.6.2 No more Gas (NmG)

A cute little personal electric vehicle (PEV) will make driving experience fun for the driver because its size, weight and fuel make it much better for the planet. This tiny car called ‘No more Gas’ or NmG, it can speeds over 75 miles per hour (Trotter, 2014). Holding just one person which means more commuters can fit on the roads and getting anywhere with shorter time. Emission can be eliminated completely when the car is cruising around 70% compared to a conventional fossil fuel-powered car. Plug in the vehicle into power supply socket to fully recharge an empty battery in 3 hours. Fuels costs are around a quarter of the price of conventional oil powered transportation. Figure 2.21 shown the NmG electric car.

Figure 2.21: No more Gas PEV (Trotter, 2014)

2.6.3 Segway PT

The Segway PT is a two-wheeled, battery powered electric vehicle invented by Dean Karmen from Segway Incorporation Team of New Hampshire. The word 'Segway' meaning *smooth transition* and PT is an abbreviation for *personal transporter* (Mr Segway, 2014). Figure 2.22 shown the full Segway PT.

This vehicle was complete with computer and motors in the base of the device that keep the Segway upright when powers on with balancing enable. Moreover, a user command the Segway to go forward by shifting their weight forward on the platform, and backward by shifting their weight backward, to turn the driver presses the handlebar to the left or the right (Mr Segway, 2014). Segway can reach a speed of 12.5 miles per hours and driven by electric motor.

Figure 2.22 Segway Personal Transporter (Mr Segway, 2014)

Speciality of Segway also designed with safety requirement to the user. It has been designed to detect a fault in any system; the Segway will warn you with a beep and shake the handlebar to reduce its speed. It has digital indicator as shown in figure 2.23 and display unhappy face if something wrong with the vehicle ("Safety In Design | Segway Safety," 2010). It also contains Balance Assembly Sensor or solid state gyroscopes which gather information about the orientation of the platform and sends it to the controller boards.

Figure 2.23: A smile face shown means Segway is ready to ride and vice versa ("Safety In Design | Segway Safety," 2010)

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Methodology

The study of wheel size in PEV performance cannot depend only on the theory itself but need also required some test regarding the factors that has been determined in the scope of study at the early stage of report. In figure 3.1 below shown the steps by steps on how to conduct the project.

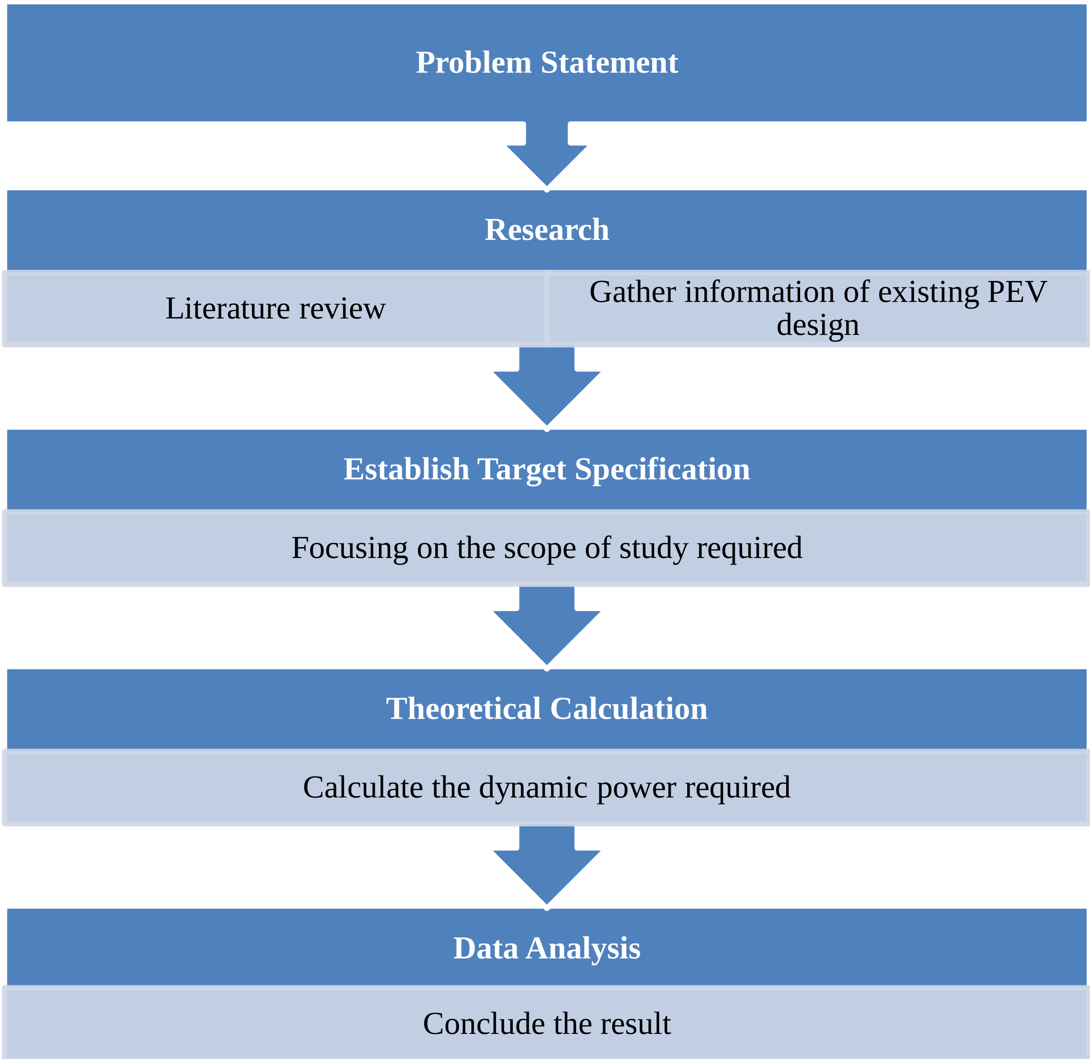

Figure 3.1 Process flow chart

The process involve in studying the dynamic analysis system of a personal electric vehicle (PEV). In order to achieve the targeted analysis, describing part by part of a drive system is crucial. The methods cover from selecting a personal transporter until achieving the desired performance.

The first step to do analysis is to study the parts which relate to the drive system of a PEV. Study will be done with different kind of transporters which have typical structure of PEV. The scope of the PEV structure consists of energy storage (battery), drive system and the wheels.

Next, the requirements for different wheels size are chosen to do the analysis based on the scope. This requirement will be based on the objective of the project that is to perform dynamic analysis and power needed by different wheel size and some specification.

The test will be conducted by calculation by using Microsoft Excel software, to do simple iteration and easy to do estimation where try and error method is performed.

Lastly, the final data or result gather from the software will be conclude and proposed the best choice of wheels size.

3.2 Theoretical Calculation

This calculation was done to determine vehicle dynamic properties such as total torque and rolling resistance. When doing this experiment, there have some assumption to achieve the objective, such as in table 3.1 below:

Table 3.1 Requirement properties of vehicle

Mass (PEV+Rider)	15kg + 70kg
Wheels radius	0.1m, 0.175m and 0.25m
Mass of wheel	0.5kg, 0.75kg, 0.9kg
Speed	0 – 20km/h in 10 second
Coefficient of Friction	Dry road = 0.7 Wet road = 0.4

To conduct this experiment is when the vehicle cruising with speed from 0 to 20km/h in 10 seconds, the coefficient of rolling resistance and torque play an important role to observe the different motion of the vehicle. This value will be used in the computational prediction vehicle dynamic by using software. The equation that will be used in this experiment consist of angular acceleration of the vehicle in rad/s^2 (α), moment of inertia (I), frictional force (F_f) and total torque (Ţ).

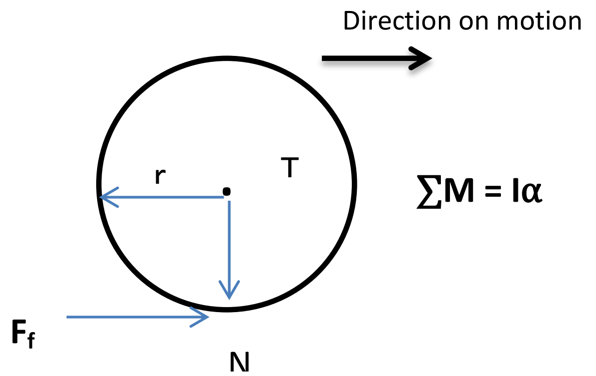

Figure 3.2 Free Body Diagram of dynamic analysis

From moment equation,

$\sum M = I\alpha$

$T - F_f r = I\alpha$

$T - \mu mgr = I\alpha$

Then, total torque require by the motor to turn the wheels,

$T = I\alpha + \mu mg$, $I = mr^2$ *(assume as thin walled hollow cylinder)*

$$F_f = \mu mg$$

$$F_{rr} = C_{rr}mg$$

Where: T = torque (Nm)

m = mass (kg)

μ = coefficient of friction (dimensionless)

g = gravity (9.81kgs)

F_f = frictional forces

F_{rr} = rolling forces

3.2.1 Microsoft Excel

With all vehicles the prediction of performance and range is important. Computers allow to do the experiment or simulation easily. Above all, computer based method allows us to quickly experiment with aspects of the vehicle, such as torque required by the motor, motor power, battery type, weight and so on. Moreover, we will see how the changes affect the performance and range by result at the end of the experiment. As standard mathematics and spreadsheet program, I will used Microsoft Excel to calculate the require parameter. The software is used to do simple iteration. Even though the function quite limited as compared to MATLAB, but Microsoft Excel is practical to use.

3.4 Gantt Chart

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Define problem : Identify problem to be studied																												
Literature Review: Doing research from the previous researcher																												
Analysis of the wheels : Identify the wheels size and analysis the importance factors																												
Establish target requirement: Focusing on the scope of study and calculate dynamic required																												
Conduct test: Start doing the experiment by using software																												
Evaluate wheels performance: Finalize the performance of each size of the wheels																												
Select wheels: The best wheel will be selected for PEV																												
END																												
Writing Final Report																												

CHAPTER 4
RESULT AND DISCUSSION

4.1 Justification

In this project, I focused on pneumatic type tire because most of the existed PEV model in the market nowadays commonly used this type of tire. Pneumatic tire have good stability while cruising. The large pneumatic tires have less rolling resistance because they will not drop into smaller holes and capacity to absorb vibration or shock over bumps. Unlike a non-deformable wheels or urethane wheel, a pneumatic tire is flexible it 'hugs' the ground for better grip and comfort.

This is important feature in choosing the right tire from the suspension of the vehicle. The rolling resistance is inversely proportional to wheels diameter for given and road materials, so larger wheels are always better. For small diameter of tire, urethane tires cast onto a plastic or metal wheel are highly efficient.

Nevertheless, there have some limitation also for pneumatic tire involves variations in air pressure and tire performance. Lower tire pressure can create improved traction and increased comfort because the tire 'flatten' slightly.

4.2 Result and Discussion

4.2.1 Total torque based on different wheels size

From this formula,

$T = I\alpha + \mu mgr$,

radius of wheel (m)	mass of wheels (kg)	moment of inertia, I	angular acceleration, α (rad/s^2)
0.1	0.5	0.0050	5.560
0.175	0.75	0.0230	3.177
0.25	0.9	0.0563	2.224

Frictional forces		total torque	
dry	wet	dry	wet
54.200	41.693	54.23	41.72
94.850	72.962	94.92	73.03
135.501	104.231	135.63	104.36

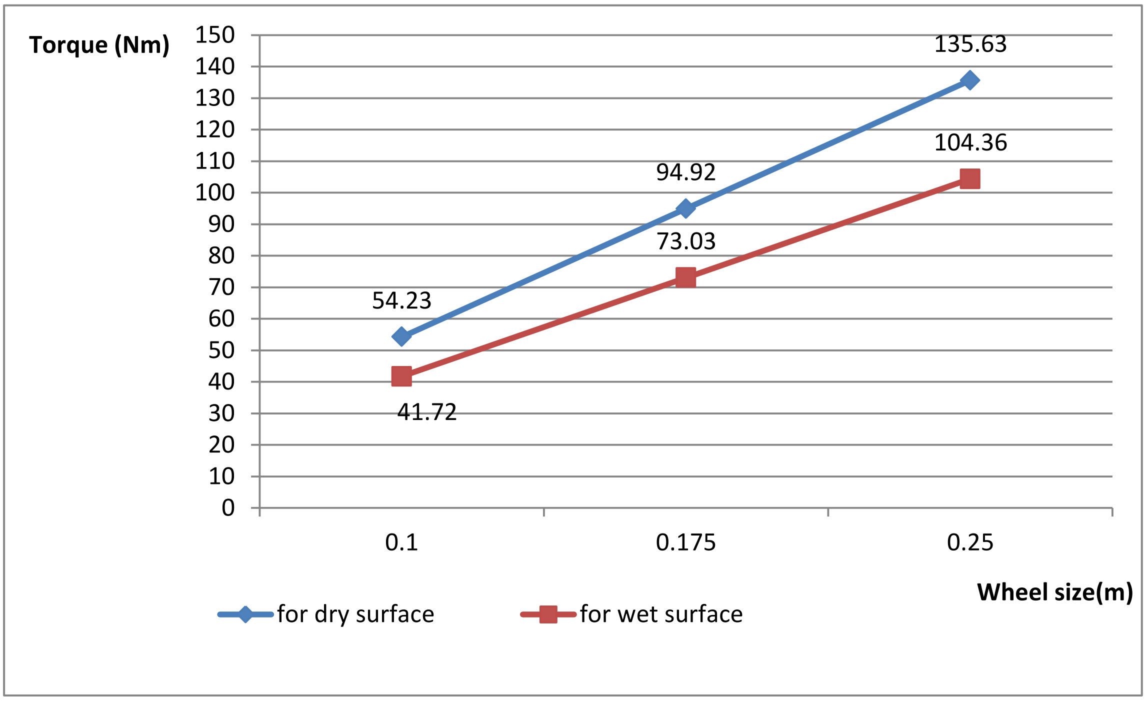

Figure 4.1: Total torque based on different wheels size

From the above figure 4.1 shown graphs of total torque versus different wheels size. With two different of surface we can observe here is at dry surface, total torque required more in dry surface because it required more friction between the wheel and the pavement surface. Whereas at wet surface, the torque is lower compare to dry surface because is more slippery and lesser torque required for the vehicle to move.

It can be observe here is the larger the wheel size the more torque required for the vehicle to move. The large value of torque is more than 130 Nm for the 0.25 m and the smallest torque approximately 40 Nm in wet surface. So the smaller size of the wheels is better to avoid higher torque of the vehicle.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

By doing some research about personal electric vehicle (PEV) on chapter 2, the writer can fully understand more about the concept of PEV and the problem related to the PEV. However, the main problem here is the wheel technology of PEV for designer or developer wants to upgrade and constructed the new PEV. The problem statement is clearly understood by the writer to execute the objectives efficiently.

The writer managed to list out the important parameter and set up the assumption made to do the calculation method by using Microsoft Excel. The different sizes of wheel have been selected based on the research. In addition since that the rolling resistance is most importance in this report. The result will determine the best wheels size to be installed on the PEV based on the scope set earlier.

From the experiment, the total torque required by the vehicle need to choose smaller size of wheel to get better performance by the torque required. This is reversible if the torque required to overcome the rolling resistance, the best wheels size is smaller the better. Moreover, in term of power, by changing the wheel size of PEV, does not affect the power of vehicle.

5.2 Recommendation

This project is to select the best wheel for the personal electric vehicle (PEV) for the designer or developer. However, this project can run smoothly with directly refers to the respective designer itself of the PEV model in the market. This is because they already have the information that already established and important information such as the speed that designer wants to achieved. By this information, the writer will do the analysis more accurately in choosing the best wheel size for PEV.

In the other hand, to get the larger simulation and better result this is best done in software such as MATLAB spread sheet. MATLAB is the most appropriate since it is very widely used, and much easier than Excel to explain what I have done and how to do it. MATLAB also can create function for calculation.

REFERENCES:

1. Afdc.energy.gov. (2015). Alternative Fuels Data Center. Retrieved 5th January, 2015, from http://www.afdc.energy.gov/laws/9355
2. Barrand, J., & Bokar, J. (2009). Reducing tire rolling resistance to save fuel and lower emissions. *SAE International Journal of Passenger Cars-Mechanical Systems, 1*(1), 9-17.
3. Blueplanetgreenliving. (2015). Green Campus Project Wants Your Vote | Blue Planet Green Living. Retrieved 18th Feb, 2015, from http://www.blueplanetgreenliving.com/2010/04/08/green-campus-project-wants-your-vote/
4. Carter, M. (2014). i-ROAD: Toyota Unveils Three-Wheeled All-Electric Vehicle Ahead of Geneva Motor Show. Retrieved 28th December, 2014, from http://inhabitat.com/toyotas-i-road-concept-is-a-three-wheeled-personal-mobility-electric-vehicle/
5. Dregni, E., & Martin, P. (2006). *Scooters: everything you need to know*: Motorbooks.
6. Ed Grabianowski. (2007). Pneumatic Tires - HowStuffWorks. Retrieved 14 February, 2015, from http://auto.howstuffworks.com/tweel-airless-tire1.htm
7. Ehsani, M., Gao, Y., & Emadi, A. (2009). *Modern electric, hybrid electric, and fuel cell vehicles: fundamentals, theory, and design*: CRC press.
8. Electric-bikes.com. (2015). An Introduction to Light Electric Vehicles (LEVs) - Electric-Bikes.com. Retrieved 8th March, 2015, from http://www.electric-bikes.com/intro.html
9. Electric powered vehicles. (2011). Retrieved 21 December, 2014, from http://www.alke.com/electric-powered-vehicles
10. Geiser Aaron. (2009). Electric Scooters vs. Gas Scooters | General Info | General Info. Retrieved 15th Jan, 2015, from http://www.electric-scooters-info.com/index.php/General-Info/electric-scooters-vs-gas-scooters.html
11. Kim, E., Lee, J., & Shin, K. G. (2013). *Real-time prediction of battery power requirements for electric vehicles.* Paper presented at the Proceedings of the ACM/IEEE 4th International Conference on Cyber-Physical Systems.
12. Larminie, J., & Lowry, J. (2004). Electric Vehicle Modelling *Electric Vehicle Technology Explained* (pp. 183-212): John Wiley & Sons, Ltd.
13. Lin, B. (2014). *Master's Thesis -- Hydrogen fuel cell scooter forurban Asia.* Retrieved from http://brucelin.ca/scooters/
14. Livesmartbc.ca. LiveSmart BC - B.C.'s Greenhouse Gas Emissions. Retrieved 8th January, 2015, from http://www.livesmartbc.ca/learn/emissions.html
15. Marshall Brain. (2010). How Lithium-ion Batteries Work - HowStuffWorks. Retrieved 29th June 2014, from http://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery1.htm

16. Mr Segway. (2014). Segway Tech. & Advanced Development. Retrieved 4th February, 2015, from http://www.segway.com/about-segway/segway-technology.php
17. Nave, R. (2010). Moment of Inertia. Retrieved 19th January, 2015, from http://hyperphysics.phy-astr.gsu.edu/hbase/mi.html
18. Nycewheels.com. Electric bikes and electric scooters : Batteries 101. Retrieved 22nd Feb, 2015, from http://www.nycewheels.com/battery-info.html
19. Patch, J. (2012). Book : The Contact Patch. from http://the-contact-patch.com/book/general/g0119-rolling-resistance
20. Patrick George. (2002). How Aerodynamics Work - HowStuffWorks. Retrieved 22 December, 2014, from http://auto.howstuffworks.com/fuel-efficiency/fuel-economy/aerodynamics.htm
21. RC Think. (2004). Brushed vs Brushless Motors. Retrieved 16th February, 2015, from http://www.thinkrc.com/faq/brushless-motors.php
22. Rockyview. (2013). Lesson 3-Magnetic and Electric Fields in Nature and Technology. Retrieved 16th March, 2015, from http://resource.rockyview.ab.ca/rvlc/physics30_BU/Unit_B/m4/p30_m4_l03_p4.html
23. Safeguardquotes.info. (2015). Sealed Lead Acid Battery Charging Basics How To Charge | Search Results | Safeguard Quotes. Retrieved 30th Dec, 2014, from http://safeguardquotes.info/tag/sealed-lead-acid-battery-charging-basics-how-to-charge-
24. Safety In Design | Segway Safety. (2010). Retrieved 21st March, 2015, from http://www.segwaysafety.com/safety-in-design
25. Study, N. R. C. T. R. B. C. f. t. N. T. E. (2006). *Tires and Passenger Vehicle Fuel Economy: Informing Consumers, Improving Performance* (Vol. 286): Transportation Research Board.
26. Szadkowski, B., Chrzan, P. J., & Roye, D. *A study of energy requirements for electric and hybrid vehicles in cities.* Paper presented at the Proceedings of the 2003 International Conference on Clean, Efficient and Safe Urban Transport.
27. Tomwoodthink.com. (2015). Tom Wood Th!nk | New dealership in Indianapolis, IN Retrieved 22nd January, 2015, from http://www.tomwoodthink.com/zero-emissions.htm
28. Trotter, C. (2014). NO MORE GAS Personal Electric Vehicle. Retrieved 21st February 2015, from http://inhabitat.com/no-more-gas-myers-motors-at-well-tech-in-milan/
29. Ulrich, K. T. (2005). Estimating the technology frontier for personal electric vehicles. *Transportation Research Part C: Emerging Technologies, 13*(5), 448-462.
30. Urban Transportation. (2014). Electric Bike and Electric Scooter Batteries - Which types? How to Choose? - Scooter Underground. Retrieved 7th Feb, 2015, from

http://www.scooterunderground.com/knowledge/Electric_Bike_Electric_Scooter_Batteries.htm
31. van Essen, H., & Kaupman, B. (2011). Impacts of electric vehicles: summary report.
32. Wakefield, E. H. (1998). *History of the Electric Automobile-Hybrid Electric Vehicles* (Vol. 187).
33. . Wheel with solid tire / aluminium / polyurethane-coated / rims (2010) (Vol. 2015).
34. WordPress. (2015). The Differences Between Gas and Electric Scooters |. Retrieved 3rd March, 2015, from http://www.elscooter.com/the-differences-between-gas-and-electric-scooters/

APPENDIXES

MATERIAL 1	MATERIAL 2	Coefficient Of Friction			
		Dry		Greasy	
		Static	Sliding	Static	Sliding
Aluminum	Aluminum	1.05-1.35	1.4	0.3	
Aluminum	Mild Steel	0.61	0.47		
Brake Material	Cast Iron	0.4			
Brake Material	Cast Iron (Wet)	0.2			
Brass	Cast Iron		0.3		
Polystyrene	Polystyrene	0.5		0.5	
Polystyrene	Steel	0.3-0.35		0.3-0.35	
Polythene	Steel	0.2		0.2	
Rubber	Asphalt (Dry)		0.5-0.8		
Rubber	Asphalt (Wet)		0.25-0.0.75		
Rubber	Concrete (Dry)		0.6-0.85		
Rubber	Concrete (Wet)		0.45-0.75		
Saphire	Saphire	0.2		0.2	
Silver	Silver	1.4		0.55	
Sintered Bronze	Steel	-		0.13	

Appendix 1: The value of coefficient of friction, μ