COMPARATIVE STUDY OF VEHICLE FUEL ECONOMY WITH AND WITHOUT ENGINE START-STOP STRATEGIES

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DECLARATION

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. The work was done under the guidance of Dr Teoh Yew Heng, at the Universiti Sains Malaysia, Engineering Campus.

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Date: 7th JUNE 2017

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

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Dr Teoh Yew Heng

Date: 7th JUNE 2017

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I cannot forget friends who went through hard times together, cheered me on, and celebrated each accomplishment: Teoh Cheng Lay, Leong Yong Sheng, Tee Kah Hui and Khiew Chee Keong.

I deeply thank my parents, Ong Ah Chai and Ng Lin Hwa for their unconditional trust, timely encouragement, and endless patience. It was their love that raised me up again when I got weary. The family of my brothers and sister have also been generous with their love and encouragement despite the long distance between us.

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Abstract

The start-stop functionality is widely used as a fuel saving solution for on-highway vehicles, being constantly studied and implemented in new series models. The subject of this work is to demonstrate the same start-stop functionality applied for city road vehicles in Malaysia. The implementation of the start-stop system in a conventional car aims for a reduction on fuel consumption and prolong the fuel economy. The start-stop behavior is recorded by using OBD-II adapter through ECU. These interventions are important discussions topics and include fuel consumption study by using forward facing model developed. The data recorded via OBD-II is analyzed and used as input in the Simulink model. The result shows that the fuel economy can be boosted up to 1.412%. This indicates that vehicle with start – stop practice can travel further with same amount of petrol when comparing to conventional vehicle.

Abstrak

Fungsi mula-berhenti digunakan secara meluas sebagai penyelesaian penjimatan bahan bakar untuk kenderaan di lebuh raya, yang sentiasa dikaji dan dilaksanakan dalam model siri baru. Subjek kerja ini adalah untuk menunjukkan fungsi start-stop yang sama digunakan untuk kenderaan jalan raya off di Malaysia. Pelaksanaan sistem mula-berhenti di sebuah kereta konvensional bertujuan untuk mengurangkan penggunaan petrol dan memanjangkan ekonomi bahan api. Kelakuan mula-berhenti direkodkan dengan menggunakan penyesuai OBD-II melalui ECU. Ini campur tangan perbincangan penting topik dan termasuk kajian penggunaan bahan api dengan menggunakan ke hadapan menghadapi model maju. Data yang dirakam melalui OBD-II dianalisis dan digunakan sebagai input dalam model Simulink itu. Hasilnya menunjukkan bahawa ekonomi bahan api yang boleh dirangsang sehingga 1,412%. Ini menunjukkan bahawa kenderaan dengan amalan permulaan -Stop boleh melakukan perjalanan lagi dengan jumlah yang sama petrol apabila berbanding dengan kenderaan konvensional.

Chapter 1 Introduction

Fossil fuel used in transportation for our daily life are highly polluting. The emissions like nitrogen gas and carbon monoxide, are harmful to environment and human. This pollution has obviously very bad impacts on human health. Against this serious problem, some developing countries are encouraging electrical vehicles under the slogan of zero emission cars. Unfortunately, these electrical cars present some technological drawbacks which are summed up on the long charging time and the autonomy. Nowadays, several fuel efficient technologies had been introduced to increase the efficiency while reduce the emissions. Like cylinder deactivation, also named as multiple displacement, displacement on demand, it will turns off some engine's cylinders when they are not needed. This essentially shuts off the intake valve to the cylinders so that air-fuel mixture did not pumped into the cylinders. The potential efficiency improvement is up to 5% [1]. Apart from that, electric vehicle is the future trend of transportation as it produces zero emissions. This contributes to climate change and smog than conventional vehicles. Implementing automated start/stop (SS) technology in a passenger vehicle is a cost effective way to improve fuel economy (FE) and reduce emissions of gases. In urban areas, most of the vehicle driving time is spent on idling at stop lights or in traffic, the engine can be shut down to save fuel. Then, the engine is quickly and quietly start back as the driver demands torque for acceleration. This operating system is often utilized in full hybrid-electric vehicles that have powerful electric systems. However, this system is becoming more popular in micro-hybrid vehicles that use traditional starter/battery configurations. It is challenging to maintain drivability and achieve efficient startups using a micro-hybrid configuration. This research investigated the feasibility of using SS strategy in term of fuel economy.

1.1 Project Background

Environmental protection and efficient energy utilization have been always important issues in the automotive industry, but have been gained significant drive with the growing demand for mobility around the world and its impact on the global environment. For this purpose, many efforts and improvements have been done in automotive technology over the past decades. However, fuel economy with improvements in vehicle powertrain technology has been stopped by customer preferences. The challenge of producing vehicles that meet future fuel economy and emissions requirements which are costly to meet the desired customer value is faced by the automotive industry.

Automakers are trying to find new ways to quickly and affordably improve the fuel economy of their vehicles to meet the new requirements. Improvements are being made to several parts, such as the engines, transmissions, and auxiliary loads of conventional vehicles. Many car makers are begin to produce hybridized vehicles where much of the powertrain architecture and auxiliary loads of the vehicle are electrified. This increases the vehicle efficiency as it is potential to recover energy that is otherwise lost in a traditional vehicle structure. Precise control of electrified components also minimizes losses during driving to improve overall vehicle efficiency.

As hybrid vehicles, due to the high cost of the electrification they introduce, in next years will not raise the average CO_2 figures in a significant way, it is favorable to introduce new cost-oriented CO_2 structures able to boost engine operations, as they offer a very satisfactory cost/value ratio.

There are significant ineffectiveness related with the conversion of fuel energy into the final drive force that drives a vehicle. Only around a quarter of the original energy is accessible to drive the vehicle after accounting for all of the energy losses involved in energy conversion, called brake energy in vehicles. The losses related to the conversion device itself, which is the engine can be reduced by thrust related improvements. However, propulsion improvements fall outside of the scope of this work.

In this project, the start/stop enabling devices will be employed on Peroduo Myvi car. In 2015 alone, Malaysia has produced 614,671 personal cars and ranked at 24^{th} place in the world car producer statistic [2]. Perodua Myvi has been the best-selling car in Malaysia for eight consecutive years, between 2006 and 2013 [3]. By practicing start-stop behavior, the fuel cost savings will be very effective and good for environment as less gas emissions.

1.2 Problem Statement

In the course of driver education activities, our country has encountered a significant that many drivers have about idling reduction. These drivers believe that turning the vehicle off and on frequently will cause premature wear of the starter system. At the same time, the fuel consumption also is a crucial criterion that the drivers concern about. They scared the on-off engine system will consume a lot of fuel compared to conventional car system. Thus, following summarize the problem statement of this title:

- Do SS technology really saves fuel compare to other conventional vehicles?
- Do the fuel cost savings of shutting down the engine counteract any potential component wear cost?

1.3 Objectives

The bulk of idling research to date has focused on the effects of vehicle idling. Most research has ignored passenger car idling as a source of emissions and wasted fuel. The main objective of this research topic is to investigate the feasibility of using SS technology as a means to increase the vehicle fuel economy.

1.4 Scope of Work

This study focused on the difference of fuel economy of vehicle with and without SS strategy. It is interested on how much of fuel been using when driving in the city. Due to technical problems, transient fuel consumption is hard to obtain. Hence, Simulink model is developed and used to determine the fuel consumption of vehicle. Simulink model verification is needed in order to prove the accuracy of the model. Drive cycle for both conditions are crucial in this study as it provided the input data for the simulation model. Last but not least, the return of investment is calculated to show that the SS technology worth to implement or not.

1.5 Gantt chart

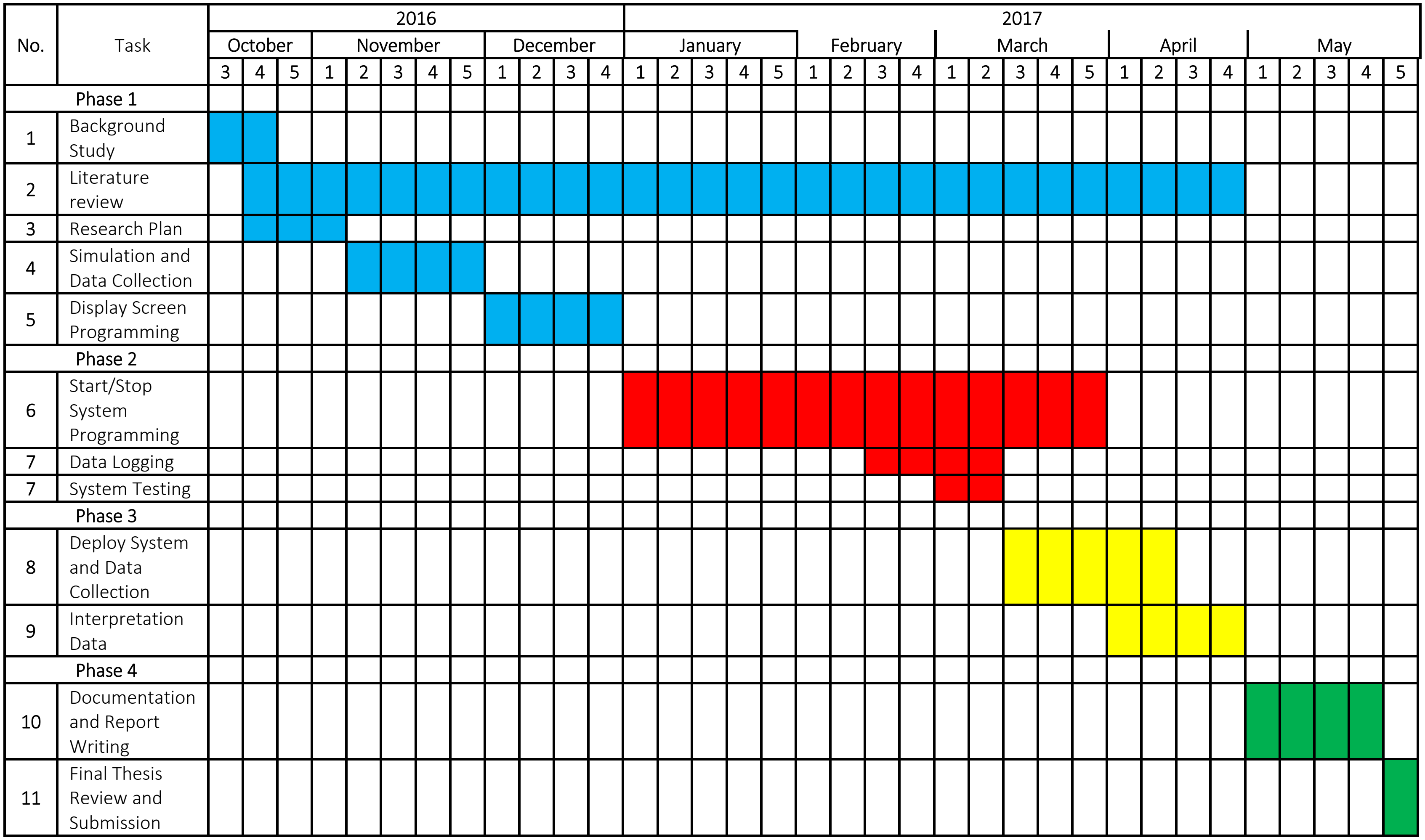


Figure 1.1: Gantt chart for the study to be carried out

Chapter 2 Literature Review

2.1 State of the Art

Start/stop (SS) is a vehicle operating strategy that turn off the engine during periods when the vehicle is not moving. This shut-off the fuel consumption that would normally be consumed to keep the engine running. The engine is not producing any usable energy to move the vehicle during the idling time, therefore the engine is technically operating at a zero-efficiency state. However, the vehicle auxiliary loads require power to sustain it even when the vehicle is not moving, making it requires a secondary energy source to supply those needs. For this reason, some SS technology had been constrained to hybrid powertrains with larger secondary power sources and electric equipment. Note that it is not necessary to limit SS to hybrid powertrains, so long as proper control is implemented. Table 2.1 shows that SS can be used with varying levels of hybridization.

Table 2.1: Various Degrees of Vehicle Hybridization [4]

		Full Hybrid	**Mild Hybrid**	**Micro Hybrid**
Functions	Electric Drive	Yes	No	No
	Torque Assist	Yes	Yes	No
	Stop/Start	Yes	Yes	Yes
	Regenerative Braking	Yes	Yes	Yes (limited)
Hardware	Electric Machine	High power electric motor	CISG, BISG	BISG, ESM
	Power Sources	High voltage NiMH or Li-Ion battery pack	High voltage NiMH or Li-Ion battery pack	Lead/acid batteries, Ultracapacitors
Hybridization cost		High	Medium	Low
Market		High end	High and middle end	Entry Level
Examples		Ford Escape Toyota Prius Lexus RX400h	Honda Civic GM VUE	Citroen C2 BMW 1 Series

SS can be implemented through all degrees of vehicle hybridization including mild and micro hybrid applications where a non-hybrid powertrain is utilized [4] [5] [6]. This can be done by adding few components, which normally includes a high-power starter, appropriate electrical system, and controller.

2.1.1 Overview of Start/Stop Systems

Many conventional vehicles, or vehicles with non-hybrid powertrains, are being well-appointed with SS. Adding SS technology to a vehicle is the lowest form of hybridization these vehicles are classified as micro hybrids. Vehicles that equipped with SS technology available in the U.S. market today include Audi, BMW, Ford, GM, Honda, Kia, Mercedes-Benz, Porsche, and others. Some of these systems will be reviewed here. Ford has introduced a SS system for their 2013 Fusion vehicle that only costs $235 to implement and has an 18-month payback [7]. This system increases the FE by 3.5%. The additional cost only comes from the insertion of an upgraded starter along with an electric hydraulic pump to maintain the internal pressure of the automatic transmission. The controls for the system closely regulate the vehicles auxiliary loads to determine when the SS function is appropriate to use. The driver acceptance is maintained by using voltage blending control when SS is available. The electrical system is unmodified and uses a lead-acid 12V absorbent glass mat (AGM) battery, which has become the industry standard for vehicles with small SS systems. Ford has proper control on the battery depth of discharge (DOD) and regulation of dynamic charge acceptance (DCA) in order to protect the 5 battery from advanced aging. DCA directly affects the amount of energy that the battery can harvest during regenerative braking. A SS system is implemented by BMW for its 3-series that uses the system to perform auto start-stop function (ASSF) and regenerative braking [8]. This system uses the traditional 12V AGM battery to gain a 3.5% increase in FE. A partial battery state of charge (partial-BSOC) is strictly managed by electrical system to maintain the battery working. The BSOC range is approximately 79-85%. The only additional components for the SS system are a battery sensor and a power management software module that controls the decision making process for SS and regenerative braking. This system runs on manual transmissions where the start and stop process are shown in Figure

2.1. Here the engine startup and shutdown is controlled by the driver engaging and disengaging the clutch.

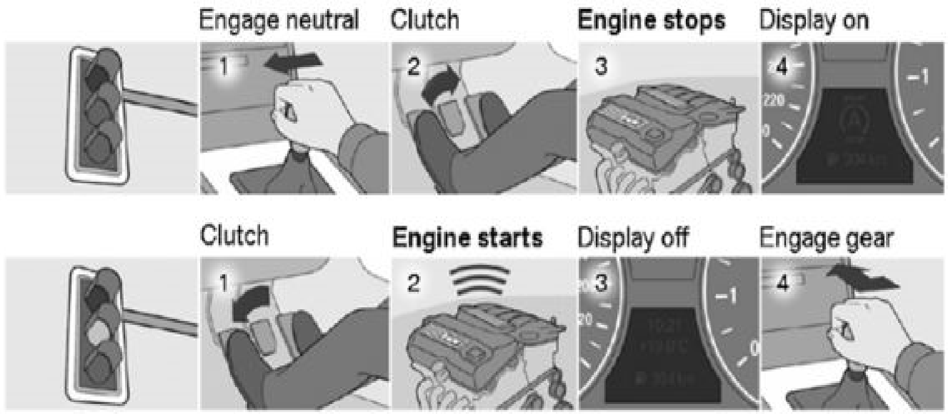


Figure 2.1: Start/Stop Procedure of BMW's with Manual Transmissions [8]

2.1.2 Start/Stop Control

The starter is the main component in a start/stop technology. As shown in Figure 2.2, it can be a conventional starter [9] [10] or an enhanced starter motor [11]

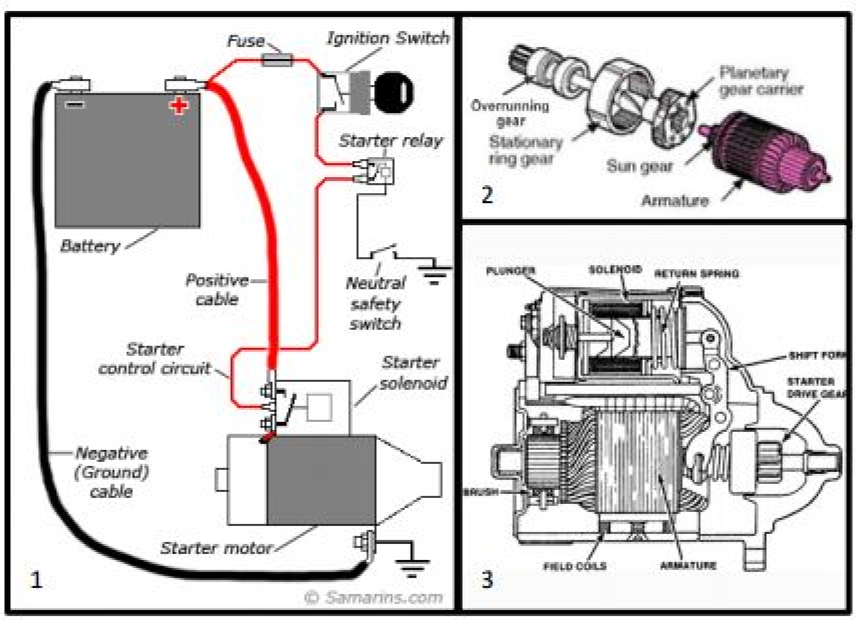


Figure 2.2: Overview of Starter System in a Conventional Vehicle [8]

Flywheel is the place where the starters mounted on and are generally smaller than 5 kW and provide less fuel economy improvement compared to the larger belted started alternator (BSA) due to lesser regenerative braking capabilities. A robust SS system will usually require a BSA. The BSA transmits power to the engine via the auxiliary serpentine belt system. The use of a bi-directional belt tensioning system is required in BSA to ensure that the belt tension is sufficient for engine starting [11] [9] [10]. A secondary power source is needed for SS in order to restart the engine and provide power to the vehicle auxiliary loads that run while the engine is off. During the idle time, if at any point the auxiliary loads become too much, the engine must be restarted so that the alternator can recharge the battery and supply power to the auxiliary loads [11]. Numerous SS events can also negatively impact the battery life [10]. Due to this, the selection of the electrical system extremely important for successful SS operation. Various combinations of batteries, ultra-capacitors, battery regulators, DC/AC inverters, and DC/DC converters will be presented in SS electrical system. Table 2.2 shows a summary of the common advantages and disadvantages for different battery compositions often utilized in vehicles.

Table 2.2: Summary of Battery Type

Battery Type	Advantages	Disadvantages
Lead Acid	Can be designed for high power Inexpensive Safe Reliable OLD ESTABLISHED TECHNOLOGY as starter battery	Poor Cold temperature Performance Short Calendar and Cycle Life
Nickel- Cadmium	High Specific Energy Good Cycle life compared with lead acid	Does not deliver sufficient power
Nickel-Metal Hydride	Reasonable Specific Energy Reasonable Specific Power Much longer cycle life than lead acid Safe Abuse-tolerant	High Cost Heat Generation at High Temperatures Low cell efficiency Need to control Hydrogen Losses
Lithium Ion	High Specific Energy High Specific Power High Energy Efficiency Good High temperature performance Low Self-Discharge	Needs Improvement in: Calendar and Cycle life Abuse Tolerance Acceptable Cost Higher degree of Battery safety

2.2 Simulation based Analysis

In recent years, several papers have published related to simulation based analysis of fuel consumption and exhaust emissions by powertrain hybridization [9] [10] [11] [12]. Most of the simulation models very depend on a map based or lookup tables based approach [12] [13] [14]. The software ADVISOR is popular as simulation tool in many papers [9] [15] [16] [17]. It uses a hybrid backward/forward approach which is closely related to the strictly backward facing approach. The backward facing approach has some defects and this had been confirmed. In the backward facing models, dynamic effects are not considered, because efficiency maps are generated by steady-state testing. On the other hand, many authors [18] yield to dynamic model can be included in a forward facing simulation model. It is also possible to model the vehicle and its components in forward facing approach [19] [20] [21]. The main drawback over the use of a forward facing approach is its large time consumption; however, it is possible to simulate a hybrid and conventional powertrain during the entire cycle with a forward facing model adequate for simulating dynamic operation of powertrains in real time.

This research presents a comparative analysis of fuel consumption of vehicle with and without SS strategy over diverse driving cycles. A forward facing simulation model of an ICE and models of other powertrain components are implemented by using MATLAB Simulink. The model is first verified before proceed to simulation using real time data. The conducted experiments aimed at providing fuel consumption characteristics in comparison with that of conventional vehicles. Finally, the total annual values of financial and environmental benefit of the SS system were calculated by using the proposed models.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This study is carried out based on the research flow chart below.

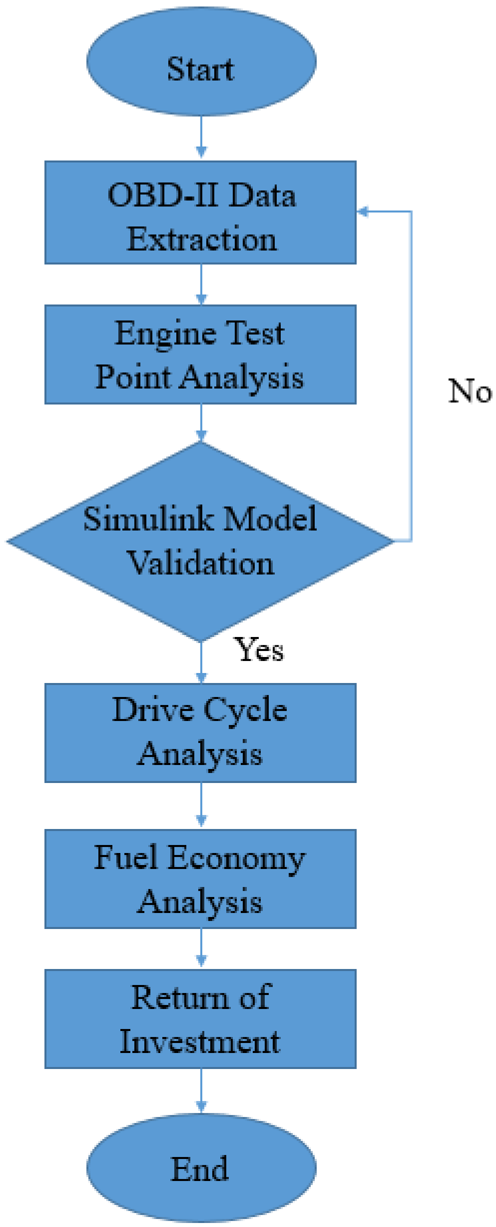


Figure 3.1: Flow chart for research study

The strategy for controlling the engine stop and restart operation consists of four main tasks:

1. Determine when the engine can be turned off
2. Control the shutdown process
3. Determine when the engine shall be restarted
4. Control the restart process

A flow chart for the process of executing the strategy can be seen in Figure 3.2.

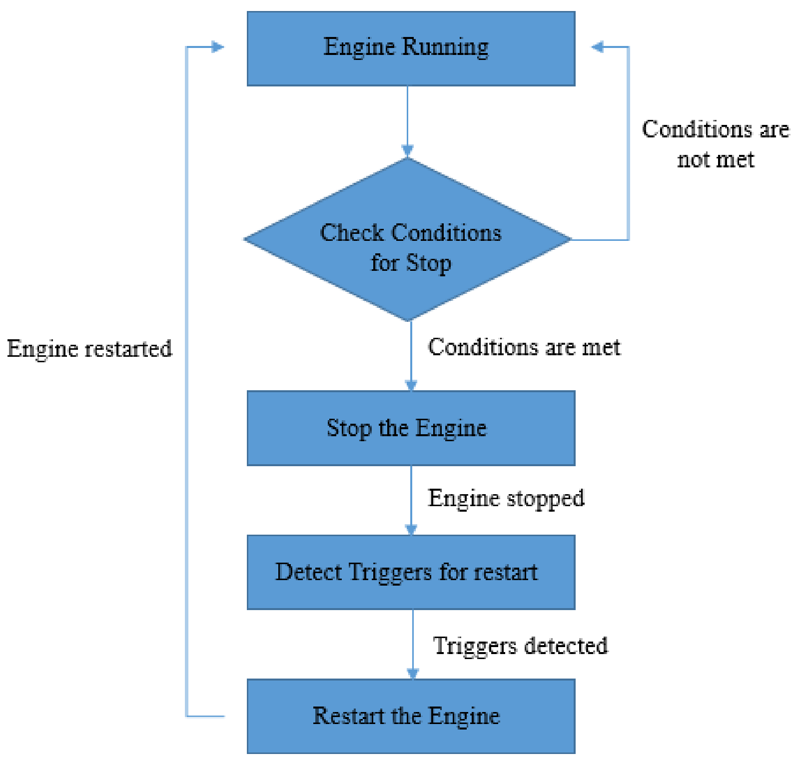


Figure 3.2: Flow chart for manual start-stop strategy

The strategy is developed and designed to be implemented in the MyVi car managing the conventional powertrain. This is done by manual shutting down the engine when the car is idling. The information concerns fuel economy like engine rotational speed, vehicle speed and so on are red by using the OBD-II Adapter and log into the micro SD card for further analysis. The torque of engine that been obtained is put into the Simulink Model for fuel economy calculation. This chapter describes the different tasks that must be performed and gives introductions to the OBD-II Adapter and signals necessary to carry out the strategy.

3.2 Vehicle Selection

Malaysia is a rapidly developing Southeast Asian country, where the demand for passenger cars increases every year. Perodua Myvi has been the best-selling car in Malaysia for eight consecutive years, between 2006 and 2013. Due to this, Myvi car has been chosen as the test vehicle as it is the most popular car in Malaysia. By applying the start-stop strategy on it, the effect of this technology on fuel consumption can be determined. The model of test vehicle chosen is Myvi 1.3 Standard G- Automatic, manufactured in year 2011. The photo and specification of the Myvi car using for testing is as shown in Figure 3.3 and Table 3.1.

Figure 3.3: Perodua Myvi 1.3 Manual Transmission for test drive

Table 3.1: Specification of Perodua Myvi 1.3 Manual Transmission and its engine [22]

Dimension & Weight			
Overall length / width / height		mm	3695/1665/1570
Interior length / width / height		mm	1850/1380/1265
Wheelbase		mm	2440
Kerb weight		kg	960
Seating capacity		Persons	5
Min. turning radius (tyre)		m	4.7
Transmission			4 E-AT
Couple distance	Front & rear	mm	869
	Driver & passenger	mm	680
Engine			
Engine type			K3-VE
Valve mechanism			DOHC, 16V with DVVT
Total displacement		cc	1298
Fuel tank capacity		Litres	40
Max. output/torque		kW/rpm / Nm/rpm	67/6000 / 117/4400

The Figure 3.4 shows the overview of the Myvi car engine. The Mvyi car uses 1.3 litre K3-VE engine with four in-line cylinders, it employs Dynamic Variable Valve Timing (DVVT) systems and conventional electronic fuel injection (EFI). In term of raw performance, features previously rare on Perodua cars were inherited from the Sirion to the Myvi. The features included four-hole injectors, foamed urethane injected to the A-pillar, centre pillar and B-pillar for noise insulation, immobilizer systems and pedestrian injury reduction body construction. Other notable features include underbody air flow regulating items, resin intake manifolds and cylinder head covers integrated with air cleaner cases and flexible flywheels for reduced vibration during running (for manual transmission).

Figure 3.4: Overview of Perodua Mvyi 1.3 liter KE – VE engine

3.2 Hardware

3.2.1 Engine Test Cell Overview

An engine test cell is built up of many inter-related components. The two primary components are the engine and the dynamometer. Each of the components requires several main inputs to produce the outputs. The overall inputs and outputs of the test cell include physical matter such as fluids and air, energy sources such as fuel and electricity, and data inputs and outputs. The flow of the system inputs and outputs is shown pictorially in Figure 3.5.

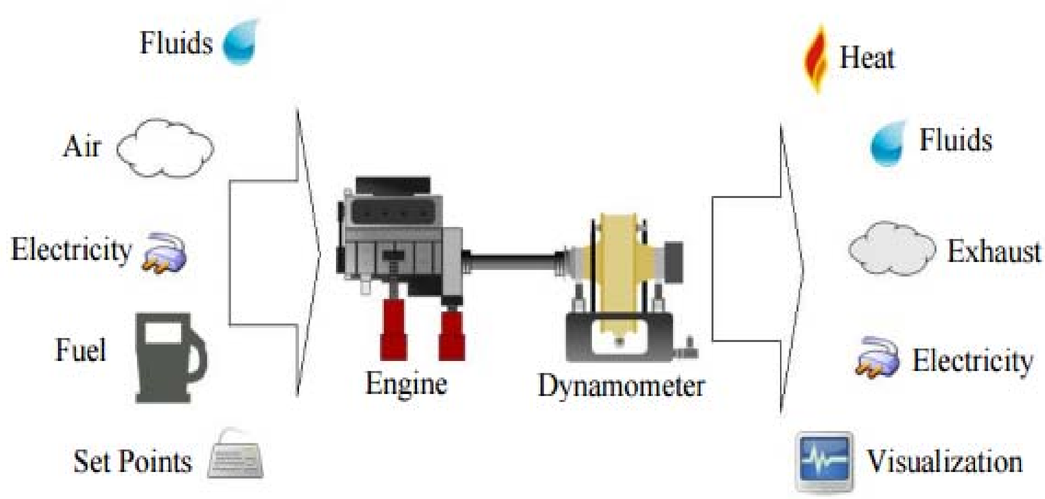


Figure 3.5: Test cell inputs and outputs

The test cell available in USM School of Mechanical Engineering is using eddy-current dynamometer coupling with Myvi engine. The Figure 3.6 shows the components of the test cell.

Figure 3.6: Test cell available in USM School of Mechanical Engineering

3.2.2 Volumetric Fuel Consumption Measurement System Overview

In order to obtain fuel consumption, the test cell is mounted with twin burettes to supply the fuel to the engine. When the engine is running, it will draws fuel from the burette and how much of fuels been used can be known. The Figure 3.7 shows the setup of the system.

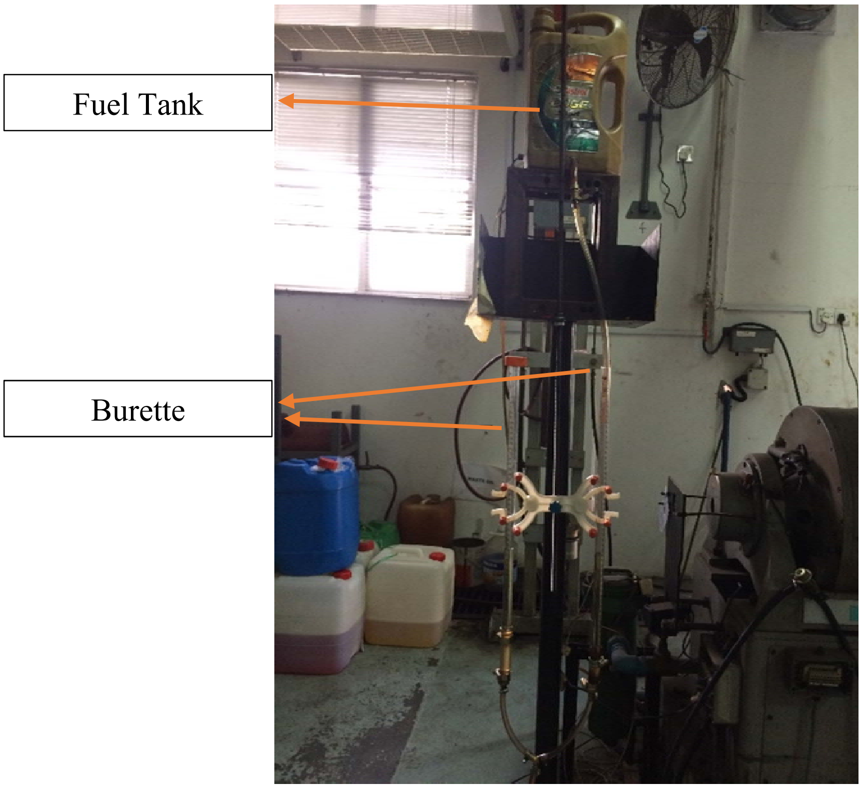


Figure 3.7: Volumetric fuel consumption system setup

3.2.3 On-Board Diagnostics (OBD) – II for Engine Control Unit (ECU)

Measurement of engine speed and vehicle speed is an important part of this research. It is required for further tests and project development to acquire fuel consumption. To keep the setup as simple as possible it was decided that hook up the OBD-II Telematics Advances Kit to the Myvi car and run the car. In this kit, there are several parts:

3.2.3.1 Arduino MEGA 2560 board

Arduino MEGA 2560 board which is directly works with Arduino IDE. It is shown in Figure 3.7. Its Bluetooth Low Energy (BLE) feature allows simple wireless data exchange with iOS and Android devices.

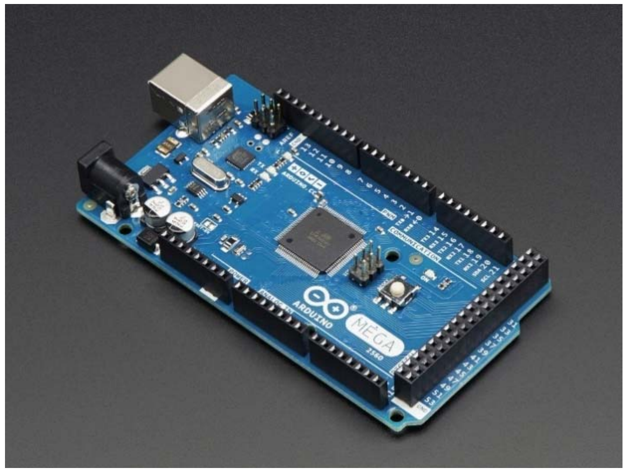


Figure 3.8: Arduino MEGA 2560 Board

3.2.3.2 Telematics Shield

Arduino Mega shield dedicated for telematics applications. Freematics 3.2″ TFT LCD Touch Display Shield is a multifunctional shield designed for Arduino MEGA and Arduino DUE with display (3.2″ color TFT LCD touch screen display), storage (microSD socket), I/O extension (two serial UART and one I2C sockets) and wireless communication (optional onboard Bluetooth Low Energy or Bluetooth 2.1 module). It can displays the basic info such as vehicle speed, engine speed on the screen after getting data from ECU.

Figure 3.9: Telematics Shield hook up with GPS module

3.2.3.3 OBD-II Adapter

The Freematics OBD-II I2C Adapter V2 provides access to OBD-II data and built-in MPU-6050 motion sensor. Apart from providing OBD-II data access, it also integrates 6-axis MEMS sensor module and voltmeter for measuring vehicle battery power. The adapter draws power from OBD-II port and convert it to 5V for powering attached device, such as Arduino.

Figure 3.10: OBD-II I2C Adapter

3.2.3.4 10 Hz GPS receiver

This GPS/GLONASS receiver module is based on U-BLOX UBX-M8030 solution with ceramic antenna in the enclosure. For retrieving geographic location (latitude and longitude, altitude), velocity, heading course and UTC time, it works with TinyGPS library on Arduino. The importance performance index of a GPS receiver is the performance rate. Most GPS in mobile phones offer an update rate of 1Hz, which means, only one set of data can be salvaged in one second. The data interval is much reduced and thus can be used for more demanding applications in GPS receivers with 5Hz.

Figure 3.11: 10 Hz GPS Receiver

3.3 Software Setup

The Arduino platform has become quite popular with people just starting out with electronics, and for good reason. Unlike most previous programmable circuit boards, the Arduino does not need a separate piece of hardware to load new code onto the board – simply use a USB cable. Additionally, the Arduino Integrated Development Environment (IDE) uses a simplified version of C++, making it easier to learn to program. IDE is used to write and upload the code to the board via USB cable connection with computer. The Figure 3.11 shows the interface of IDE. The program is wrote and compiled in IDE. Next, it is uploaded to the Arduino MEGA through USB connection.

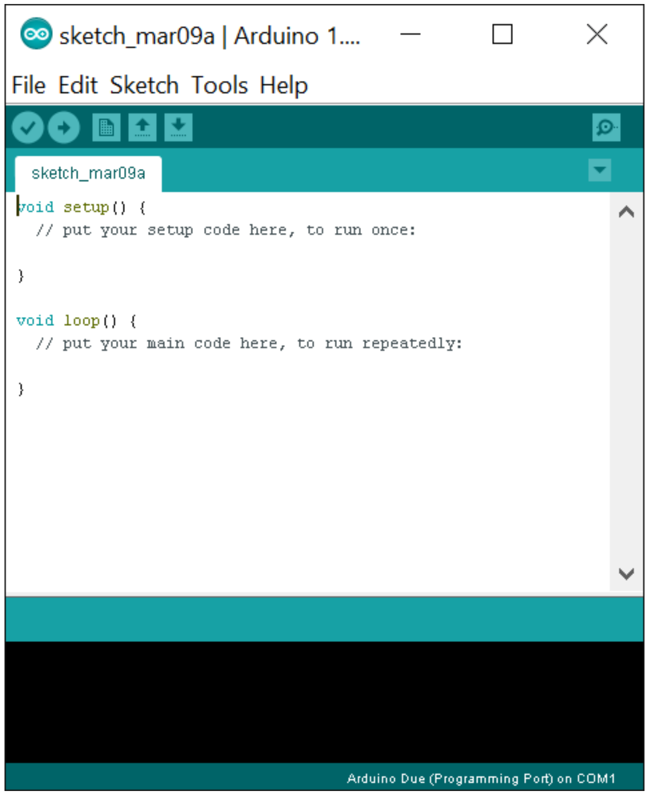


Figure 3.12: Interface of Arduino IDE

3.4 Test Procedure

For simulation model validation, a Perodua Myvi is obtained and hook up with OBD-II adapter. The following main parameters need to be logged and analyzed:

a) Engine Speed (RPM)

b) Vehicle Speed (km/h)

The vehicle is then drive at several cruising speeds and start to record the OBD data. The data is then processed and will be used to carry out engine test point analysis and model simulation. Engine test point analysis, this is to determine the power required for a giving cruising speed. Using the power data, it can be run with the dynamometer test cell to get the fuel consumption of several cruising speed for 60 seconds to compare with simulation model data. The results will be further discussed in Chapter 4.

3.5 Simulink Model

A Simulink model is developed to determine the fuel economy of a vehicle using MATLAB. Simulink is a block diagram environment for multidomain simulation and Model-Based Design. It supports simulation, automatic code generation, and continuous test and verification of embedded systems. Figure 3.13 show the forward-facing longitudinal vehicle dynamic system model. The model consists of components that are used to make the system functional as realistic as possible in longitudinal manner which are arranged in a subsystem. The components used are engine system, torque converter, transmission system, traction force converter system, gear selection system, fuel analysis system, vehicle dynamics system, experimental speed system and average fuel consumption system. The input is the torque data and the output is drive cycle. In this work, fuel economy is the main target output. The full description of the model can be found in Appendix A.

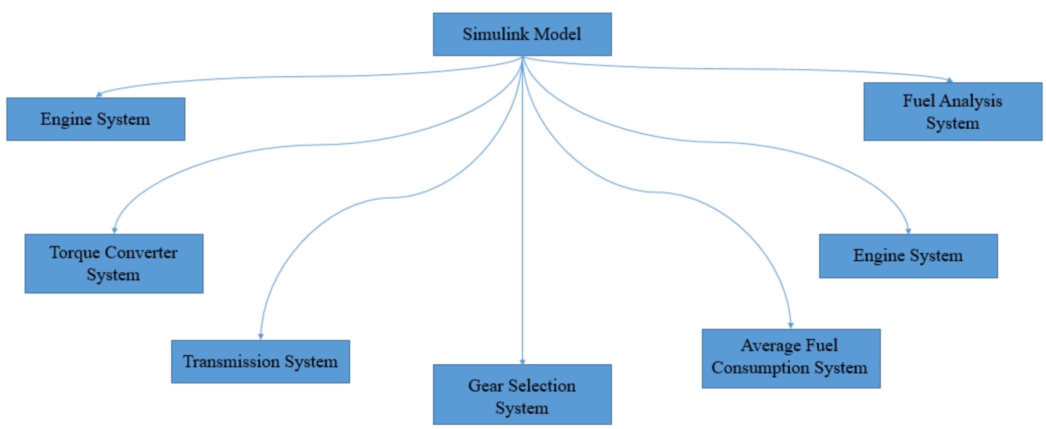
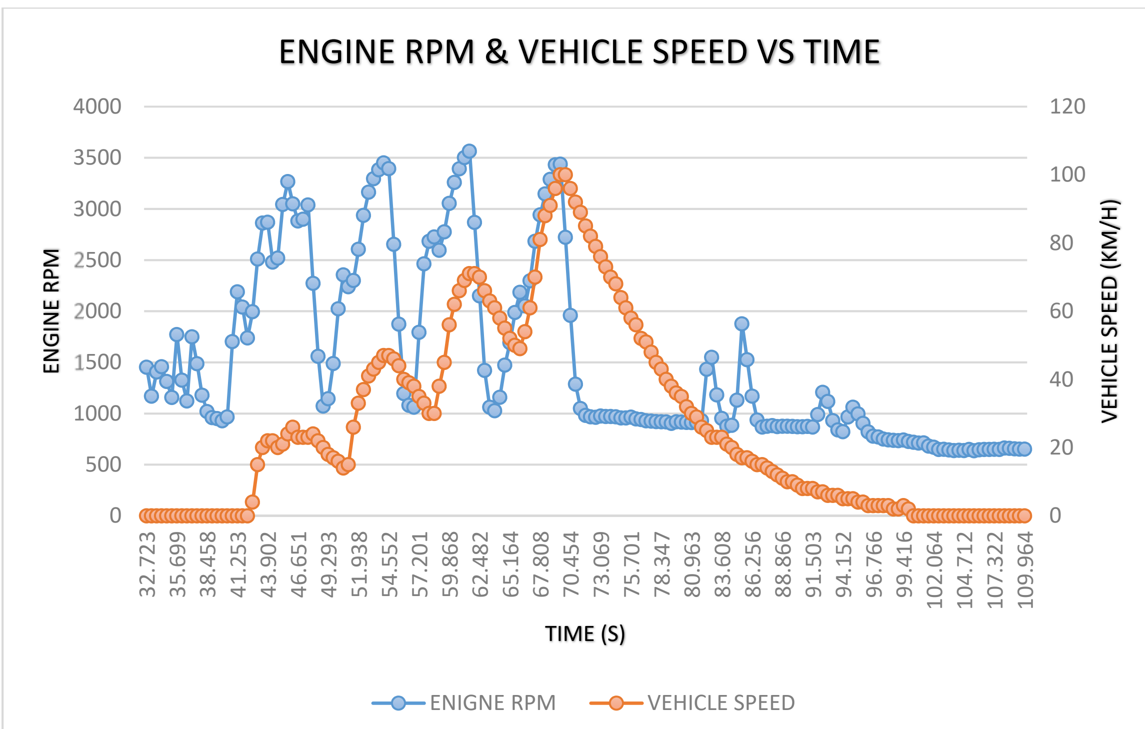


Figure 3.13: Simulink Model components

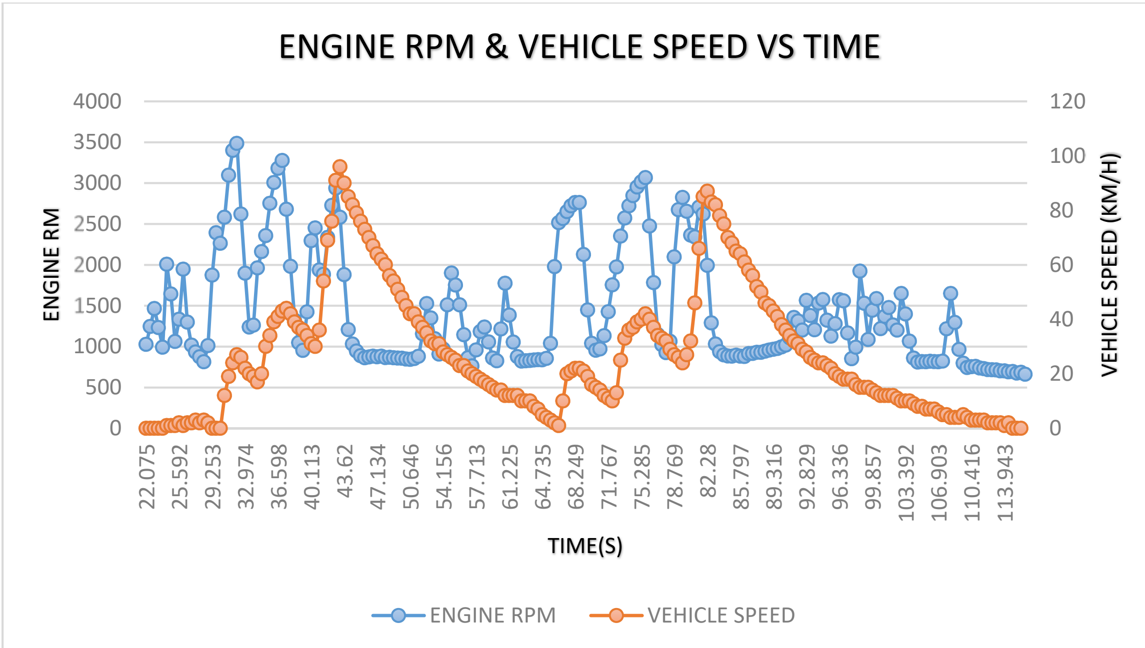
Chapter 4 Result and Discussion

4.1 Engine Test Point Analysis

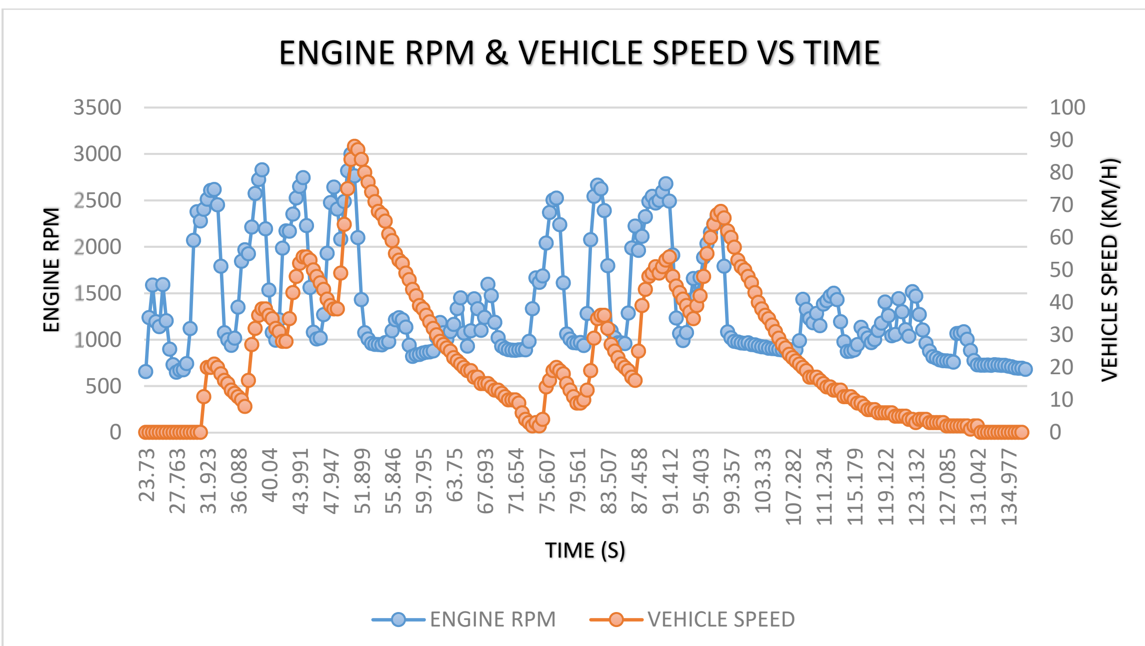
The crucial operational area for fuel consumption is at intermediate speed and torques used while cruising. Thus, the data extracted from OBD-II adapter had been plot out as engine speed and vehicle speed as a function of time. The vehicle was running 3 trials to get average values of engine and vehicle speed. The Figure 4.1 (a) – (c) show the operating value of the engine. From the figures, the engine speed and vehicle speed show ascending then descending trends. This is affected by the phenomena of gear shifting. When the gear is changing, the engine needs to slow down to engage with the new gear and boost up to match its speed.



(a): 1st trial for vehicle test run



(b): 2nd trial for vehicle test run



(c): 3rd trial for vehicle test run

Figure 4.1 (a) – (c): Engine Speed and Vehicle Speed as a function of time for 3 trials

To calculate the engine torque, the data for 5 speeds had been tabulated. The table is as follow:

Table 4.1: Engine speed (RPM) for 5 different cruising speed

Speed (km/h)	**Engine RPM**			**Average**
	1	**2**	**3**	
20	2519	2160	2510	2396
30	2605	2451	2543	2533
40	3163	2403	2350	2639
50	2865	2608	2649	2707
60	3259	2704	2487	2817

A model of the car was developed to determine the power required for a given cruising speed (Equation3). The model includes rolling resistance (Equation 1) and aerodynamic drag (Equation 2). The torque is determined by the power and the engine speed (Equation 4).

Rolling Resistance (F_{rr}):

$$F_{rr} = mgC_r \qquad \text{——————} \qquad \textbf{Equation 1}$$

Where m = Total mass of vehicle and driver, kg

g = Gravitational force, ms^{-2}

C_r = Rolling Coefficient

Aerodynamic Drag (F_d):

$$F_d = \frac{\rho_a A V^2 C_d}{2} \qquad \text{——————} \qquad \textbf{Equation 2}$$

Where ρ_a = density of air, kg/m^3

A = Frontal Area of Vehicle, m^2