ESTIMATION OF POLLUTANT CONCENTRATIONS AT ROAD INTERSECTION IN SERI ISKANDAR

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by

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CERTIFICATION OF APPROVAL

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Civil and Environmental Engineering Programme
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Approved by,

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September 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD ZAID BIN MOHD MUKHTAR

ABSTRACT

Air pollution is one of the major environmental problem, which becomes a concern to public health. The origin of the air pollution is mostly from combustion engines regardless of type and size of the engines. The main pollutant gases produce by the combustion engine are carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (HC) and nitrogen oxides (NO_x). There is few research conducted to investigate emitted pollutant at a road intersection. At the road intersection, a vehicle normally will experience deceleration, idling and acceleration, which would contribute to air quality problem. Pollutant from idling vehicle at the road intersection are likely will give significant impact to the quality of air. Hence, it is important to identify the most polluted emission and the concentration level of harmful pollutant whether it gives significant impact on safety and health for people at the road intersection perimeter. The aim of this study determine the concentration level of carbon monoxide (CO) and carbon dioxide (CO_2) at signalized intersection of the study area. Data sampling of traffic count was carried out on one-week period at the traffic light of study area located in Seri Iskandar, Perak. From the data sampling also, this study aims to model the CO and CO_2 emission at traffic light intersection by using SIDRA software. Knowing the pattern of pollutant concentrations by using the emission model might give a huge advantage in designing traffic light intersection to be more efficient. In order to control the total time of delay at the road intersection and minimize concentration of pollutant gases, recommendation or suggestion can be made such as to use sensor or detector to detect the presence of traffic or to replace the traffic light with a roundabout.

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INTRODUCTION

1.1 Background of Study

The earth, with a radius of 6400 km is surrounded by the atmosphere, which is divided into a series of layer, influenced by the temperature (Fenger & Tjell, 2009). Below 20 km height is called troposphere and followed by stratosphere or ozone layer (Figure 1). Mesosphere lies above the stratosphere, where the temperature is lower. At the atmosphere, mesopause area is where the lowest temperature reached and will rise again in the thermosphere. Atmosphere has no exact border to space but assumed to extended to a height of 80,000 km, which is much more than the radius of the earth itself (Fenger & Tjell, 2009).

Basic composition of the atmosphere is about 20 % oxygen, 78 % nitrogen, 1 % argon and varying minor concentration of series of gases (Davis & Cornwell, 2013; Fenger & Tjell, 2009). Oxygen and nitrogen, as well as other noble gases (argon, neon, helium, krypton) are present in constant concentration. The composition of the atmosphere is a large constant as a results of global circulations including emissions, transformation and reaction with other compounds.

The global carbon cycle is one of the example for the global circulation include physical, chemical, and biological processes. The carbon dioxide concentration may vary a few percent as the yearly variation of the photosynthesis and overlaid by an increasing trend of fossil fuel used. Methane and nitrous oxide also have similar increases in concentration while sulphur dioxide and other compounds have the larger variation that also appears as pollutant (IPCC, 2001, 2007).

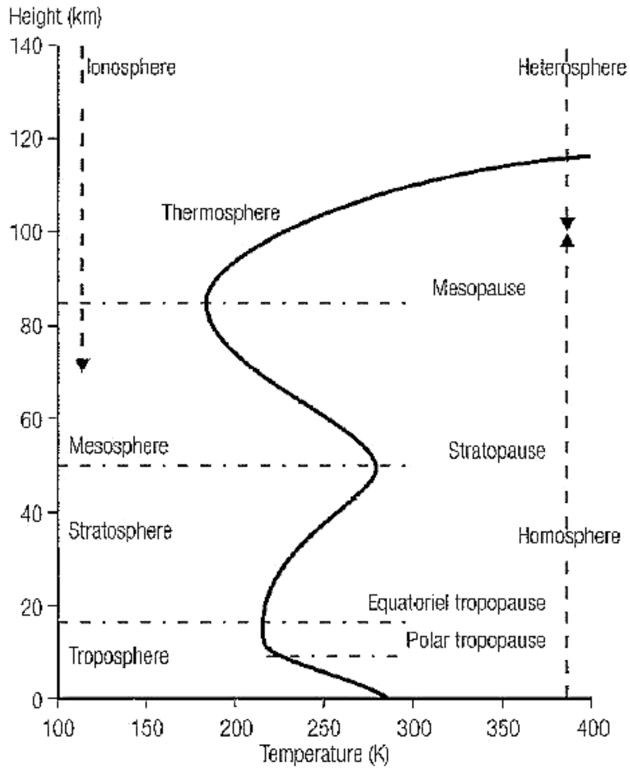

Figure 1: The atmospheric layer (Fenger & Tjell, 2009)

Carbon dioxide (CO_2), methane (CH_4), ozone (O_3) and nitrous oxide (N_2O) are the example of greenhouse gases. Greenhouse gases (GHGs) is related to incoming solar radiation that enters the atmosphere and some of it will reflected by clouds, some absorbed by atmosphere while some approaches the earth as shown in Figure 2. The energy from solar radiation must be radiated back but since the earth is colder and happen to have longer wavelength (IR), the atmosphere absorbs better due to presence of the greenhouse gases. A greenhouse gas with three or more atoms, for example H_2O and N_2O, would be able to absorb IR radiation at specific(s) causing low bending vibration in the gas molecules. The energy absorbed in the atmosphere is re-irradiated in all direction as IR radiation heats up the earth and this is called greenhouse effect (Fenger & Tjell, 2009; IPCC, 2007).

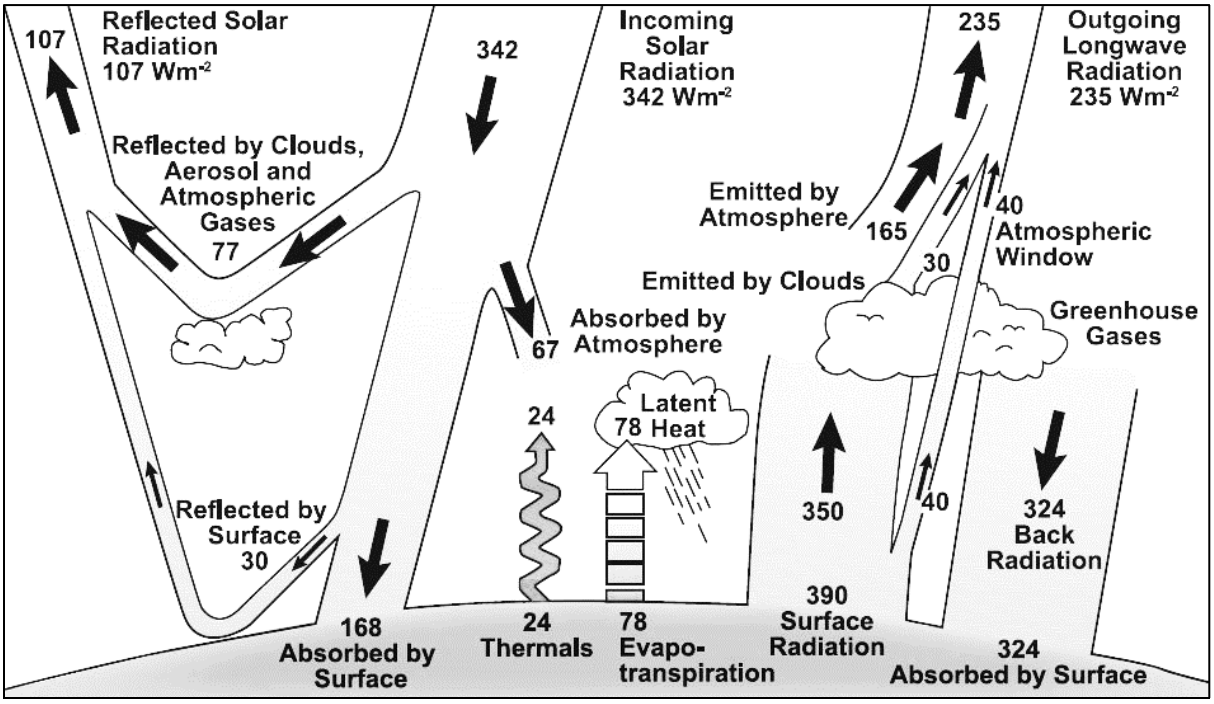

Figure 2: The incoming solar radiation in the atmosphere (Fenger & Tjell, 2009)

The greenhouse effect what make living on earth possible because it is important to keep the temperature of earth to not fall under the freezing point of water (IPCC, 2007). However, it is the industrial human activities such as burning coal, cooping down forest and making cement enhance the greenhouse effect. In the last 40 years, the global human emission of CO_2 has nearly doubled and increased the atmospheric concentration correspondingly (Fenger & Tjell, 2009; Knutti & Rogelj, 2015). CO_2 is the most important greenhouse gas that becomes the world's concern as the atmospheric concentration of CO_2 keep on increasing. The rate of increase of CO_2 concentration is about 1.5 parts per million (ppm) or 0.4 % per year over the past two decades (IPCC, 2001). Carbon dioxide has a lifetime overall approximately 100 years, which means emitted carbon dioxide is mixed into the atmosphere over the entire globe regardless the location of emission and contribute to the air pollutant (Davis & Cornwell, 2013).

Air pollution can be classified into two categories, which are the primary pollutants and the secondary pollutants. Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO) fall under the primary pollutant while ozone (O_3) is the secondary pollutant (Davis & Cornwell, 2013; Fenger & Tjell, 2009; Penney, 2008).

Ozone is one of the greenhouse gases, which is a very reactive gas formed by the action of ultraviolet light on oxides of nitrogen and hydrocarbon (Hester & Harrison, 1998).

Air pollution is mostly affected by human activities such as fossil fuel burning, toxic burning and wood burning (B.C. Air Quality, 2016.). Traffic is the main source of CO, where incomplete combustion of fossil fuel took place (Fenger & Tjell, 2009; Penney, 2008). As shown in Figure 3, the number of car in Malaysia keep on increasing every year. The origin of the air pollution is mostly from combustion engines regardless to type and size of the engines (Fenger & Tjell, 2009). The main pollutant gases produce by the combustion engine are carbon monoxide (CO), unburned hydrocarbon (HC) and nitrogen oxides (NO_x) (Pulkrabel, 2003). Gases typically measured in parts per million (ppm), parts per billion (ppb) or parts per trillion (ppt). CO level produced by internal combustion engines area varies from 10,000 ppm to 70,000 ppm or more (Penney, 2008).

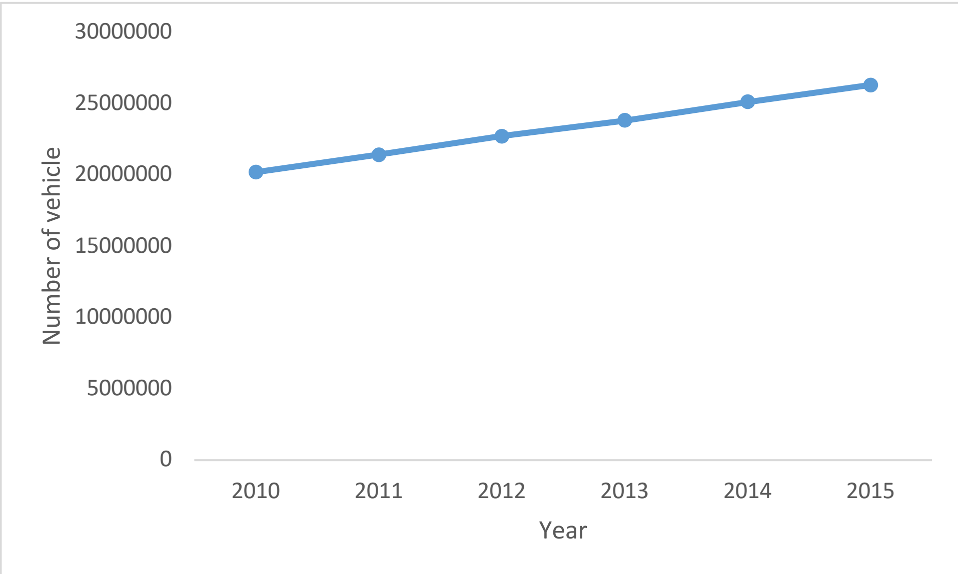

Figure 3: Number of registered vehicle in Malaysia (Department of Roads Transport Malaysia, 2016)

In the combustion engine, type of fuel also gives a significant contribution to the amount and type of the emission. European emission standard (Euro) is a globally accepted standards for vehicles that required the use of fuel. ‘Euro 1’ was first introduced in 1992, to reduce carbon monoxide (CO) emission and the latest ‘Euro 6’ standard was introduced on September 2014 to reduce pollutant up to 96% compared to the 1992 limit (Euro Emission Standard, 2015). Following guideline of Euro 1, both gasoline or petrol engine and diesel engine should emit not more than 2.72 g/km of

CO. Compare to Euro 6 standard, petrol engine should produce not more than 1.0 g/km of CO and diesel engine should produce lower CO concentration to 0.5 g/km. From the Euro 6, it is known that petrol engine would emit more CO compare to the diesel engine.

Pollutants emitted from vehicle not limited at highway or traffic jam but also including traffic light intersection cause by idle condition of the car before the light turns green. In comparison, signalised intersection or traffic light was found to consume more fuel and emit more CO in comparing to roundabout intersection (Alkhaledi, 2015). Fuel used and carbon dioxide emission from vehicle are always greater for idling over 10 seconds (Argonne National Laboratory, 2016).

1.2 Problem Statement

Gasoline and diesel fuel are used in the engine to move the vehicle and form by-product of the combustion process and contribute to the air pollution. Therefore, driving a car become the most polluting activities by a typical citizen (US EPA, 1994). Fossil fuel, which is contain hydrogen and carbon atoms that shall produce water and carbon dioxide as combustion process happen while nitrogen in the air remain unaffected.

Carbon dioxide practically is the end product of combustion of fuel while carbon monoxide is product formed by incomplete combustion of fossil fuel. Both carbon CO_2 and CO are colourless and odourless regardless the concentration (Fenger & Tjell, 2009; Hester & Harrison, 1998; Penney, 2008). High level of CO produced in internal combustion engines because of the brief period available period to complete combustion (Penney, 2008). The catalytic converter that used in petrol fuel to convert CO into CO_2 thus lower CO concentration in exhaust gases but it only works effectively when they are hot and not effective at cold start (Penney, 2008).

Recently, idle emission from the vehicle at road intersection have received attention from many researchers. However, in Malaysia, there is very limited research done for regarding emission from vehicle during idling position. The large number of vehicle in Malaysia would requires traffic light intersection is used to avoid collision at the road intersection. Rate of emission of pollutant gases by those vehicle during idling at traffic light intersection is crucial to be determined. Idling a vehicle for more than 10 seconds would consumes more fuel compared with restarting it (Rahman et al., 2013). Argonne National Laboratory (2016), claimed idling a vehicle for more than 30 seconds should produces more CO and CO_2.

Pollutant from idling vehicle at the road intersection are likely will give significant impact to pedestrian or nearby public place such as school. Hence, it is important to identify the most polluted emission and the concentration level of harmful pollutant whether it gives significant impact on safety and health of people at the road intersection perimeter.

1.3 Objective

The objectives of this study are as follow:

1. To determine the relationship between number of vehicle and emission of carbon monoxide (CO) and carbon dioxide (CO_2) at the road intersection.
2. To analyse concentration level of CO and CO_2 at the road intersection of the study area using SIDRA analysis.
3. To study effect of light vehicle (LV) and heavy vehicle (HV) to the concentration of emission at the road intersection.

1.4 Scope of Study

This study will be conducted at the signalized road intersection with the traffic light, where vehicle is usually decelerating approaching the intersection, idling and accelerate to initial constant speed. The selected traffic light should near to the public area to satisfy the need of this study with a significant result. Number of vehicle pass through the intersection should be take into account as to analyse the relationship with the polluted emission. The emission of interest for this study include carbon monoxide (CO) and carbon dioxide (CO_2). The result of this study should be able to model the CO and CO_2 emission at the traffic light intersection due to number of vehicle.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Air pollution is one of the major environmental problem, which becomes a concern to public health. The U.S Environmental Protection Agency (US EPA) has identified 166 categories of major sources and 8 categories of area sources for the hazardous air pollution including fuel combustion, metal processing, agricultural chemicals production, petroleum and natural gas production and refining (Davis & Cornwell, 2013).

In Malaysia, a study by Department of Environment (DOE) showed that motor vehicle, stationary sources and open burning had been identified as major sources of air pollution. Emission from motor vehicle or fossil fuel contributed about 70 % - 75 % of the total air pollution while emission from stationary sources contributed 20 % - 25 % (DOE, 2005). Malaysia's air quality is continuous monitoring by a private company, Alam Sekitar Sdn Bhd (ASMA), which has 51 monitoring stations that collect CO, SO_2, NO_x, O_3 and PM_{10}.

The number of vehicle that increasing every year would keep the road busy most of the time and signalised intersection is important at road intersection to avoid collision. Figure 4 shows the cycle of vehicle movement approaching the road intersection. At the road intersection, vehicle will move in constant speed before experience deceleration, idling and acceleration (Qian, Lun, Wenchen, & Meng, 2013). During idling stage, more CO and CO_2 are produce in the meantime waiting for traffic clearance. Effectiveness of traffic light intersection should be studied so emission of CO and CO_2 at the road intersection can be modelled and controlled.

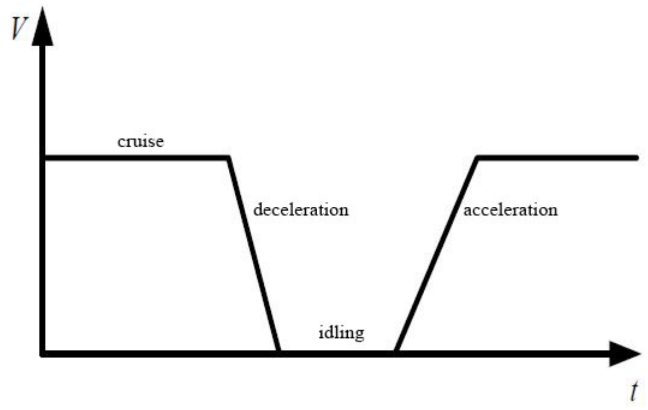

Figure 4: Cycle of vehicles speed approaching the intersection (Qian et al., 2013)

2.2 Carbon Monoxide

Carbon monoxide (CO) are colourless and odourless regardless the concentration and it is impossible to detect by humans (Fenger & Tjell, 2009; Haber, 2016; Hester & Harrison, 1998; Penney, 2008). CO is mainly formed in combustion engines, where oxygen supply is not sufficient (Fenger & Tjell, 2009). Incomplete combustion is the inevitable result of incomplete oxidation of carbon (Davis & Cornwell, 2013; Hester & Harrison, 1998; Penney, 2008). Gasoline and diesel fuels are mixtures of hydrocarbon consists of hydrogen and carbon atoms. In perfect engine or perfect combustion, oxygen in the air would convert all the hydrogen in the fuel to water and all carbon in the fuel to carbon dioxide (US EPA, 2012).

2.2.1 Physical and Chemical Properties of Carbon Monoxide

Carbon monoxide is an important industrial gas consist of one carbon and one oxygen atom. Carbon monoxide are colourless and odourless regardless the concentration (Hester & Harrison, 1998; Penney, 2008). Besides flammable and highly in toxic gas, carbon monoxide also a good reducing agent in chemical industry (O'Leary, 2000). Physical and chemical properties of carbon monoxide are summarized in Appendix 1.

2.2.2 Source of Carbon Monoxide

Carbon monoxide (CO) is a product of incomplete combustion or oxidation of carbonaceous materials or substances mostly used for fuel burning or internal combustion of engines. Besides that, CO also produce by open burning activity, coal and aircraft emission (Fenger & Tjell, 2009; Jaffe, 1968; Penney, 2008).

In a perfect combustion engine, oxygen in the air will convert all the hydrogen to water and all the carbon to carbon dioxide (CO_2), while nitrogen remain unaffected. In an automotive engine, the combustion process cannot be perfect thus it emits several type of pollutant (US EPA,1994). CO usually formed during cold start of engines, restart and idle vehicle. Table 1 shows comparison of emission such as THC, NO_x and CO during cold start, restart and idling of vehicle.

Table 1: Comparison for emission from Cold Start, Restart and Idling (Argonne National Laboratory, 2016)

Emission	**Tier 2-Bin 5[a]**	**Cold Start**	**Restart**	**Idle 30 second**	**Cold Start ÷ Restart**
THC (mg)	878	191	44	8.0	4.3
NO_x (mg)	552	228	6	0.3	38
CO (mg)	31,290	2,970	1,253	3.2	2.4

[a] Total over 7.45-mi UDDS cycle

If all pollutants are combined, except CO_2, CO emission will exceed that especially in urban environment. Estimated about more than 87 million tonnes of CO was emitted in United States alone in 1966 (Jaffe, 1968). CO reacts with ozone (O_3) and can be oxidized in lower atmosphere but in a very slow rate. However based on a study, despite increasing source of CO emission, CO concentration do not appear to increase drastically (Jaffe, 1968; Penney, 2008).

2.2.3 Effect of Carbon Monoxide

Carbon monoxide (CO) gas has a potential health hazard because high exposure to CO can affect critical body organ, such as the brain, nervous tissue and heart. CO affect both healthy and unhealthy people but most likely to give more impact on people with some type of heart disease (US EPA, 2016). Concentration of CO higher than 35 ppm should be consider toxic with continuous exposure over eight hours (Haber, 2016; Penney, 2008).

Exposed to CO might be dangerous because CO molecules that enter human body will absorb easily into the bloodstream and bind with haemoglobin (Hb) around the body in the red blood cell (Hester & Harrison, 1998; Penney, 2008). Haemoglobin has a greater affinity for CO compare to oxygen. Carboxyhaemoglobin (COHb) formed easily, where about 95% of the CO readily binds with Hb (Davis & Cornwell, 2013; Penney, 2008). Mild exposure of CO, between 35 ppm to 200 ppm, for over 2 hours will effect flu-like symptoms such as headache, sore eyes and runny nose (Haber, 2016; Penney, 2008).

2.3 Carbon Dioxide

Carbon dioxide (CO_2) is the most important greenhouse gas that becomes the world's concern as the atmospheric concentration of CO_2 keep on increasing. The rate of increase of CO_2 concentration is about 1.5 ppm or 0.4 % per year over the past two decades (IPCC, 2001). Carbon dioxide has a lifetime overall approximately 100 years which means emitted carbon dioxide is mixed into the atmosphere over the entire globe regardless the location of emission. About half of each year's CO_2 emission absorbed by ocean and land but other half remain in the atmosphere (Knutti & Rogelj, 2015). Natural feature like forest did absorbed carbon dioxide from the atmosphere but large amount of carbon dioxide released may reduce the ability or effectiveness to convert all carbon dioxide to oxygen (IPCC, 2001, 2007).

2.3.1 Physical and Chemical Properties of Carbon Dioxide

Carbon dioxide consist of one carbon and two oxygen atoms, which is present in the atmosphere by respiration and combustion. Carbon dioxide concentration keep on increasing every year has become a global attention as it is one of the greenhouse gases that also contribute to air pollution (Hester & Harrison, 1998; Knutti & Rogelj, 2015). Carbon dioxide is an acidic oxide and produces carbonic acid when reacts with water as shown in equation (1) below:

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (1)$$

Besides water, carbon dioxide also soluble in ethanol and acetone (O'Leary, 2000). Physical and chemical properties of carbon dioxide are summarized in Appendix 2.

2.3.2 Source of Carbon Dioxide

Carbon dioxide is a by-product of normal cell function, which is removed via lungs through exhaled air. Carbon dioxide naturally produced by decomposition, ocean release and respiration. Carbon dioxide also practically is the end product of combustion of fuel. Gasoline and diesel fuel are mixtures of hydrocarbon contain hydrogen and carbon atom (US EPA, 1994). The balance chemical equation off the simplest hydrocarbon fuel is methane (CH4) burning with stoichiometric oxygen or theoretical oxygen (Pulkrabel, 2003). It takes two moles of oxygen to react with one mole of fuel and should give one moles of carbon dioxide and two moles of water vapour as shown in equation (2) and (3) below:

$$\text{Hydrocarbon} + \text{Air} \rightarrow \text{Carbon Dioxide} + \text{Water} \quad (2)$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (3)$$

2.3.3 Effect of Carbon Dioxide

Man-made CO_2 emit about 30 Gigatonnes (Gt) to the atmosphere every year increasing CO_2 concentration in the atmosphere (IPCC, 2007). The rate of CO_2 concentration increase is about 1.5 ppm or 0.4 % per year over the two past decades (IPCC, 2001). CO_2 in the atmosphere is not really a bad thing for the Earth because CO_2 as one of the greenhouse gasses slowing the rate of heat loss and benefits to make life on Earth possible (Kennedy, 2009). However, increasing human activities resulting the huge amount of CO_2 released to atmosphere will trap more heat in the atmosphere and increase the world temperature. Besides affecting air quality, carbon dioxide emission also increasing acidity of seawater as CO_2 absorbed by the ocean (Kennedy, 2009). For more than a millennium from now, both past and future carbon dioxide emission will continue to contribute to global warming and sea level rise (IPCC, 2007).

In terms of health, inhaling lower concentration may not harmful to body but the higher concentration can affect respiratory function and central nervous system as it can displace oxygen in the air. Lack of oxygen enter the body can cause headache, vomiting and even worse it could create damage important organ including the brain (Davis & Cornwell, 2013).

2.4 Emission by Type of Engine

CO and CO_2 are emitted by both type of petrol and diesel engine. Both fuel are produces from crude oil but undergo different refining method (EIA, 2016). Gasoline or petrol fuel is a mixture of components that evaporate in different temperature resulting different component mixture in each cylinder of an engine. Diesel engines usually designated for some intended use including bus, truck, railroad and marine transportation (Pulkrabel, 2003).

From the overall engine concept, a diesel engine is more efficient compare to petrol engine. Generally, diesel engine have a combustion efficiency of about 98 %, while petrol engine are about 95 % efficient (Pulkrabel, 2003). For every litre, diesel containing more energy compared to petrol and make the combustion process more efficient. Diesel fuel contains 15 % more energy by volume than petrol, which make diesel denser than petrol. Therefore, diesel engine produce more CO_2 compared to petrol engine. For comparison, 1 kg of diesel would produce 2.65 kg of CO_2 while 1 kg of petrol produce 2.3 kg of CO_2 (Colls, 2002).

2.5 Research Octane Number

RON stands for Research Octane Number which define a fuel quality and performance rating. RON also refers to stability of the fuel, where the higher number of octane number tend to have more stable combustion. RON also represent the 'knock resistance' of the fuel which is a term used for premature ignition or detonation (Ramajunam, 2016). Knocking is not a good thing in combustion engines because the fuel in combustion chamber ignite (self-ignition) before it supposed to. Normal engines use a spark plug to ignite the air-fuel at the proper time in the cycle, therefore self-ignition (or pre-ignition, or auto-ignition) is not desirable (Pulkrabel, 2003). Knock or ping phenomenon can cause damage to the engine as high pressure pulses are generated when self-ignition occurs often or higher than desirable (Pulkrabel, 2003). In the recent car market, including performance cars, will have knock sensors and automatic programming to reduce knock (Ramajunam, 2016).

In Malaysia, RON 95 and RON 97 are mostly used by user for their vehicle, while some is using RON 100, which just introduced to Malaysia market early January 2016. PETRON as one of the market player in Malaysia also had launched Petron Blaze 100 Euro 4M fuel on January 2016 and available at selected station in Klang Valley and Johor (Ramajunam, 2016). Generally, to get more performance of engine, more air, more fuel and aggressive ignition are needed to compress the fuel-air mixture. The higher octane fuel is needed to compression more stable fuel detonation (Aswan, 2016). Usually, the car manufacture will specify minimum RON for engine to prevent detonation and damage to the engine. High RON number is the ability to run the engine at the high compression ratio and advance ignition timing (Ramajunam, 2016).

PETRONAS Dagangan Berhad (PDB) as PETRONAS fuel distributor has launched its new PETRONAS PRIMAX 97 that meet Euro 4M specification on August 2015 (Mesra, 2015). In September 1, 2015, BHPetrol Malaysia had introduced Euro 4M RON 97 at all BHPetrol station. Euro 4M fuel is more clean and greener fuel compared to Euro 2M as it comes with lower benzene, sulphur content and Reid Vapour Pressure (RVP) level. Euro 4M is expected to produced less pollutant and emission (Mesra, 2015). Malaysian Standard (MS) for unleaded Euro 4M actually has been discussed in several years earlier, which is the year 2011 under MS 118-3:2011, Motor Vehicle Gasoline – Specification – Part 3: Unleaded Euro 4M.

2.6 Critical Analysis

There was several research done related to emission of pollutant at the road intersection, which concern about sulphur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2) and oxides of nitrogen (NOx).

Bhandari, Parida, and Singh (2013) conducting a research in Delhi, India focusing on carbon footprint from the traffic due to idling at signalised intersection. The survey was conducted at 3 intersections, which divided as low, medium and high volume intersection. 24-hour classified traffic volume and turning movement survey was conducted at high and medium volume intersection and 16-hour traffic surveys were conducted at low volume intersection to know the traffic volume at the intersection. The research examined delays at each intersection for different type of modes of travel while calculating fuel consumption were performed by using combination of flow detector (FP series) and flow meters (DF series). Bhandari et al. (2013) did not explain in details regarding the FP series and DF series besides stated that it was according to international standard for carbon footprint of products (ISO 14067). The outcome of research indicates that idling of vehicle anticipated 9 % of the total CO_2 emission from transportation sector in Delhi in year 2004.

A different research in Kuwait by Alkehdi (2015) to measure the environmental impact of a smart roundabout on vehicle fuel consumption and emission of CO, CO_2, NO_x, and HC. Results from this research were then compared with those traditional roundabout and traffic light intersection. Two busy intersection in downtown Kuwait City were selected in this study. The traffic flow data was collected for one week using recorded video images without considering to weather condition. Results from visual data collection showed traffic volume for both morning and afternoon peak hour were almost identical as four conservative 15-minutes periods in which the greatest number of vehicle was observed. The SIDRA software is then being use to model and analyse traffic flow at signalised intersection, non-signalised intersection and roundabouts. Outcomes of the study shows there was 16.05 % less fuel consumed at the roundabout compared to the traffic light intersection.

Zhang, Lv, and Wang (2013) interested on developing model for emission at the road intersection during constant acceleration and linearly decreasing acceleration of vehicle. All data for this research are collected at two different intersections in Texas and emission of interest in this research are carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxides (NO). During data collection, acceleration trajectories from vehicle is collected to develop the acceleration model for the first 30 seconds. All the drivers were instructed to maintain their driving behaviour so it can reflect the average drivers. The constant acceleration model (Model 1) had overestimation of emission because assumption of the constant acceleration during acceleration process, while in reality acceleration decrease as speed increase. Model 2 is using linearly decreasing acceleration and Model 3 is SIDRA model (Zhang et al., 2013). Finding from this research showed that SIDRA model is most suitable for estimating emission at an intersection. SIDRA model can provide a single acceleration function without knowing individual trajectories of vehicle at an intersection.

Qian et al. (2013) has established an optimized emission model in the intersection. The author did critique some existing research, which lack of standardization of intersection model. Emission of pollutant at road intersection produced by process or cycle of vehicles movement on the road, which include idling, accelerate and decelerate emission should be taken into account for model development. The research focused on emission of pollutant CO, CH and NO at the road intersection. However, this research evaluated the effectiveness of the model and algorithm by using a numerical calculation method only. There is no sampling data being done to support the calculation or the numerical calculation provided.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter elaborates the research methodology conducted to obtain concentration levels of air pollutants at the traffic light intersection in two different intersections in Seri Iskandar, Perak. Number of vehicle that passing the traffic light was counted for a week, from 9 October 2016 until 15 October 2016 (Sunday to Saturday) during typical peak hour (7am - 9am, 4pm - 6pm). Collected data ware tabulated using Microsoft Excel and analysis of data using SIDRA Intersection software to identify the trends of pollutant. The emission of interest for this study are carbon dioxide (CO_2) and carbon monoxide (CO).

3.2 Study Area

Sampling was conducted at the main intersection in front of Universiti Teknolgi PETRONAS (UTP), Perak. As shown in the Figure 5, the traffic intersection for this study is located at Lebuhraya Ipoh-Lumut. This intersection is selected because it may provide consistent number of traffic since this intersection located nearby university area where office hour is applicable and correlate with selected time for this study. This intersection is three-leg approached or T-junction controlled by traffic light.

Figure 5: Traffic light intersection for data sampling (Google Map, 2016)

Figure 6 shows number of lanes at the intersection from all three approaches which are Ipoh approach, Lumut approach and UTP approach. Continuous turning or movement is available for Lumut-UTP direction and UTP-Ipoh direction.

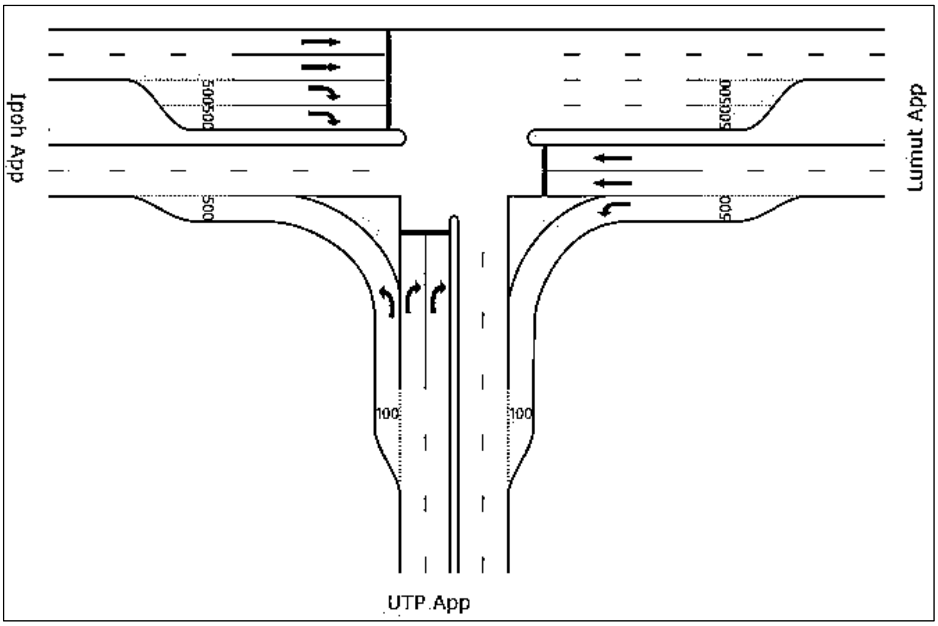

Figure 6: UTP intersection

3.3 Data Collection

3.3.1 Data Sampling

Video traffic was recorded for a week, 9 October 2016 until 15 October 2015, during typical peak hour (7am - 9am, 4pm - 6pm). The data was collected without considering any weather condition. From the video recorded, number of traffic using the traffic light intersection were collected and catalogued into 15-minute periods. From the results of observation, peak hour was defined as the four consecutive 15-minute period in with greatest number of vehicles. During the data sampling, vehicles are divided into several classes of vehicle:

Class 1 – Motorcar and taxi
Class 2 – Van and utilities
Class 3 – Lorries (2-axles) and large vans
Class 4 – Lorrie with 3-axles
Class 5 – Buses
Class 6 - Motorcycle

From all 6 classes of vehicle, it will divide into light vehicles (LV) and heavy vehicles (HV) for SIDRA analysis. Heavy vehicle is any vehicle with three axles and more (Akcelik, 2011). Thus Class 4 (lorries, trucks, semi-trailers) and Class 5 (buses) are classified as heavy vehicles. All other classes (Class 1, 2, 3 and 6) are defined as light vehicle.

3.3.2 Equipment

The equipment used in this study were DSLR camera and smart phone. Both devices are used to record the video traffic throughout the sampling period. The camera was placed at the pedestrian bridge located about 150 m from the intersection. Recorded video is then being reviewed and studied to count the number of vehicles per hour crossing the intersection.

3.4 Data Analysis

3.4.1 Microsoft Excel

Collected traffic data were tabulated by using Microsoft Office Excel. Microsoft Excel is used because it has a user friendly interface and can be used to arrange the data properly.

3.4.2 SIDRA Intersection Software

For modelling purpose, the SIDRA Intersection software program will be used for analysing of traffic flow and emission rate. The software inputs including the road geometry, number of traffic counts, and turning movement. The SIDRA software program uses a set of equation that use vehicle parameters, road grade and relevant speeds to generate fuel consumption and emission rate for CO and CO_2 at the road intersection.

3.4.3 Data Analysis by Using SIDRA Intersection

Figure 7 shows SIDRA interface when user open the software by double clicking on SIDRA icon on computer desktop. A temporary Project (New Project – 1), which is created automatically should be display on the left side on screen.

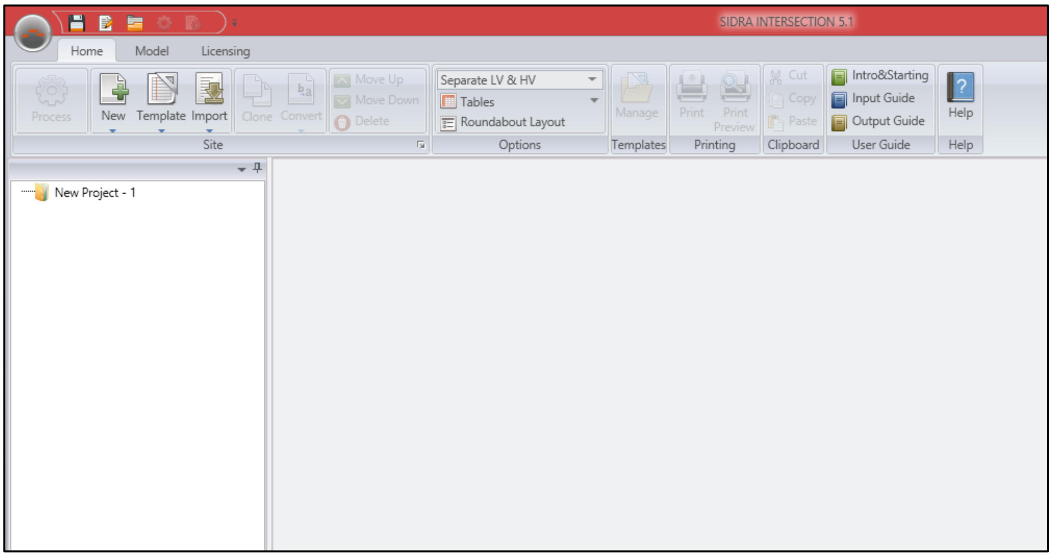

Figure 7: SIDRA Intersection user interface

To create an intersection layout for the first time, click **New** in top ribbon of the SIDRA and click **Signal** as shown in Figure 8.

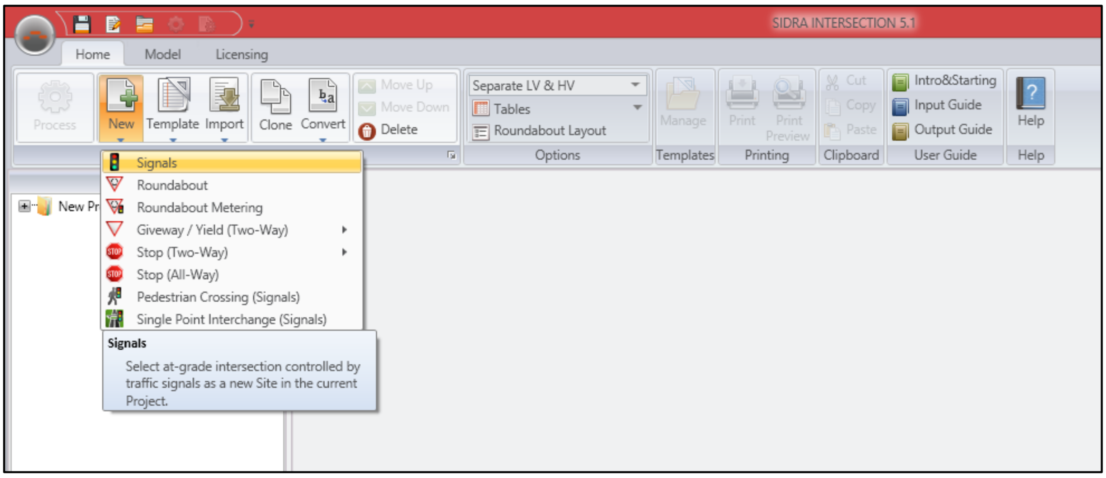

Figure 8: Existing template of different type of intersection

The Project Pane on the left-hand side should display the main nodes including Layout, Data Summary, Input and Output as shown in Figure 9. To input any data for a site or intersection, double-click on the desire nodes in the Input group.

Double-click **Intersection** (Figure 9) under Input folder on the left-had side to customize intersection either with various design and number of intersection. In the geometry picture on the main screen show exist intersection in red and intersection approach that do not exist are shown in white.

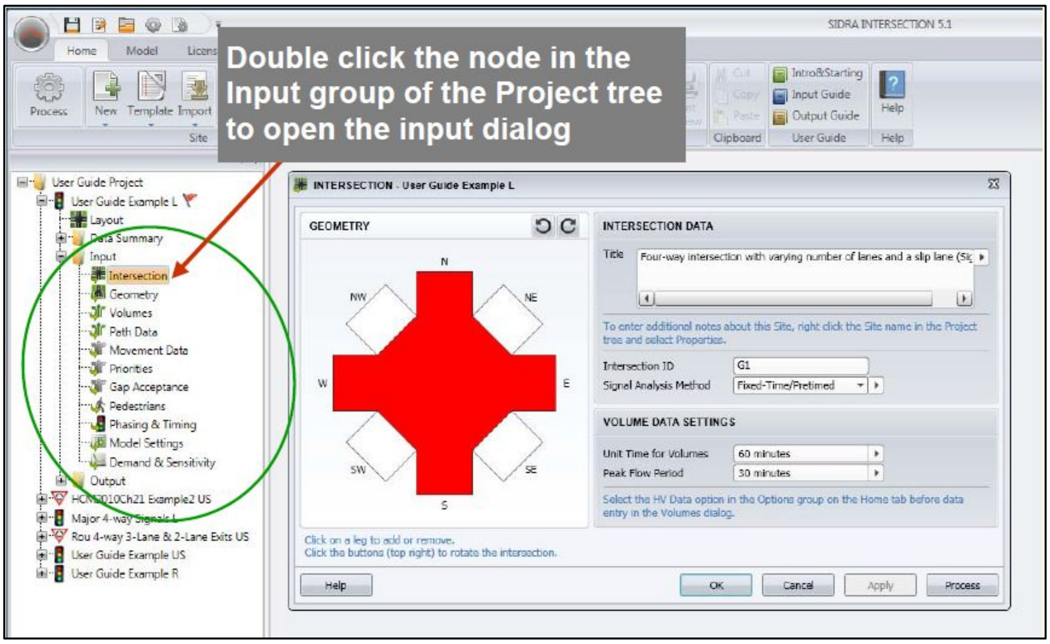

Figure 9: Intersection input interface (Akcelik, 2011)

Details design of intersection can be done in **Geometry** input dialog (Figure 10) where changes including road name, adding lane, lane separator, lane type, movement definition, type of lane and length of lane can be made.

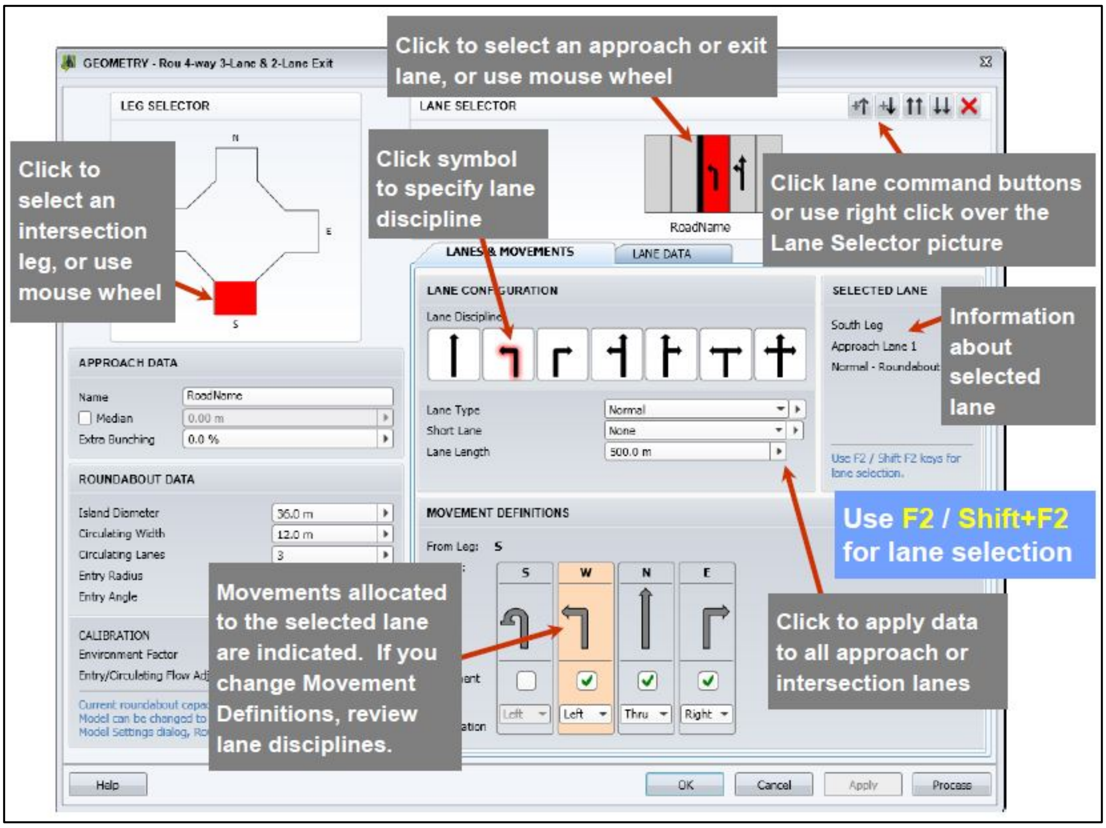

Figure 10: Geometry input dialog (Akcelik, 2011)

Lane type for selected lane can be specified using **Lane Type** drop-down list as shown in Figure 10. Example of lane type is shown in Figure 11. There are several types of lane can be choose as listed below:

- Normal
- Slip (Giveway/Yield)
- Slip (Stop)
- Signalised Slip
- Continuous

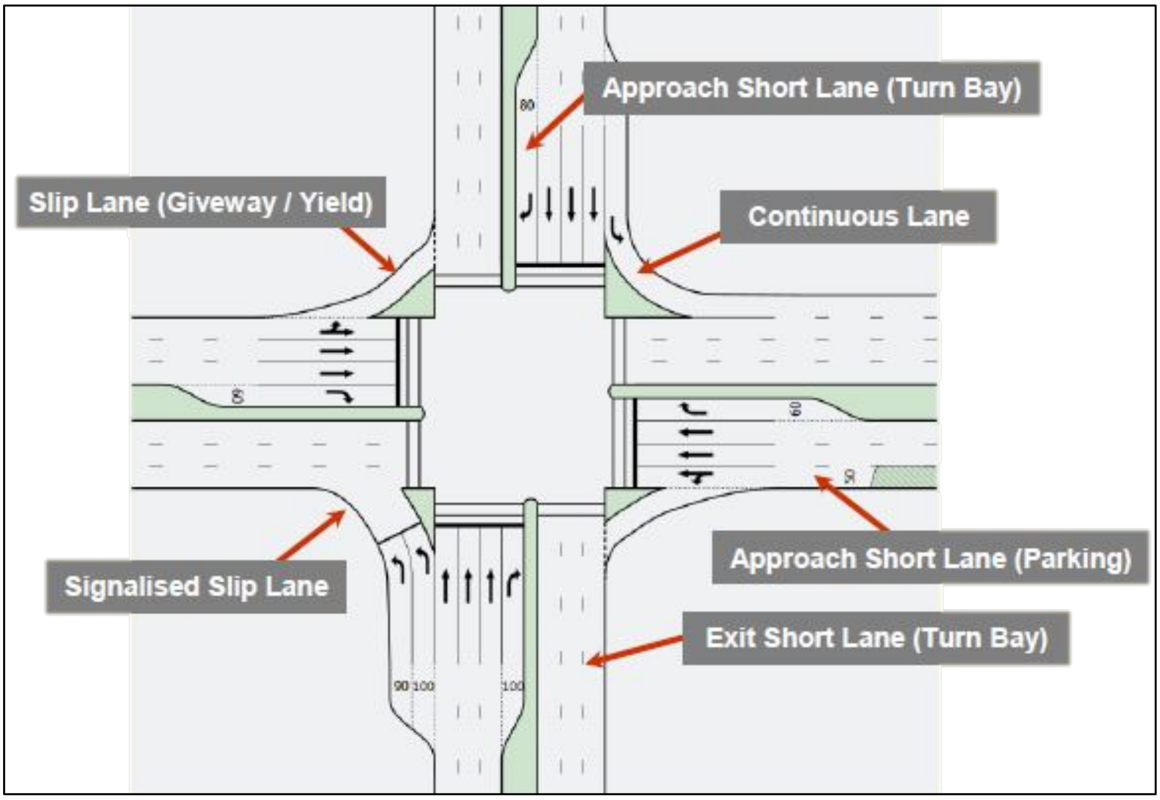

Figure 11: Type of lane at the road intersection (Akcelik, 2011)

Next, go to **Option** group in ribbon on top side to classify input data and the volume display by using the drop-down list as shown in Figure 12. The three options available as follow:

1. Separate LV & HV
2. Total Vehicle & HV (%)
3. Total Vehicle & HV (veh)

For this study, Separate LV & HV option is chose to separate volumes for light vehicles (LV) and heavy vehicles (HV). Volume for LV and HV also be represent in vehicle per hour (veh/h). Click **Volume** under Input folder on the left-hand side to input the vehicle data for 60-minutes period. Key-in the volume of vehicle based on collected data for LV and HV as shown in Figure 12. Change the **Peak Flow Factor** and **Growth Rate** (Figure 12) if necessary but for this study, it was 1.2 person per vehicle (pers/veh) and 3 % respectively.

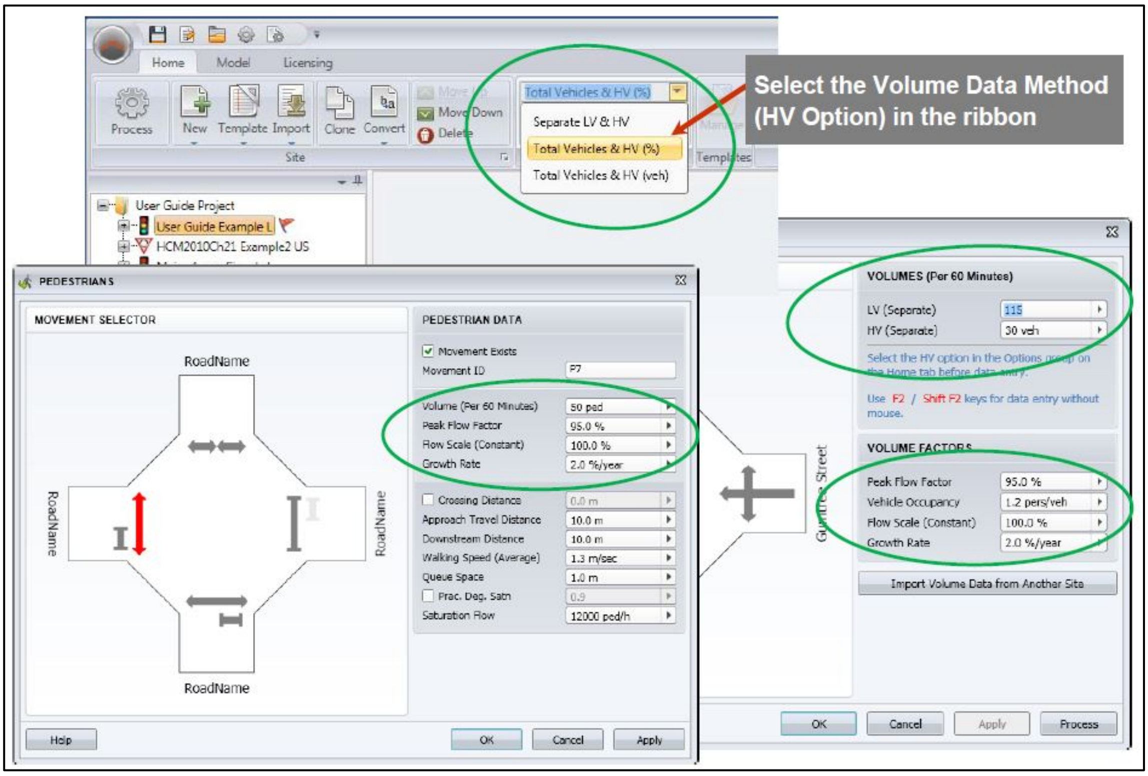

Figure 12: Volume data setting (Akcelik, 2011)

After all data has been input, click **Process** on the ribbon at the top (Figure 7) to process a site input data and create output. A new folder named **Output** should appear on the left-hand side of the screen. Double-click the Output folder and several nodes would appear including Detailed Output, Intersection Summary, Movement Summary and Lane Summary. Click **Intersection Summary** and output regarding the intersection performance would appear in table form as shown in Figure 13.

Intersection Performance - Annual Values		
Performance Measure	**Vehicles**	
Demand Flows (Total)	2,227,200	veh/y
Delay	876,739	veh-h/y
Effective Stops	5,311,452	veh/y
Travel Distance	1,615,573	veh-km/y
Travel Time	898,852	veh-h/y
Cost	23,719,790	$/y
Fuel Consumption	1,623,566	L/y
Carbon Dioxide	4,074,716	kg/y
Hydrocarbons	8,656	kg/y
Carbon Monoxide	165,695	kg/y
NOx	4,987	kg/y

Figure 13: Example of SIDRA output

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Data sampling of number of vehicle was carried out for a week at the study area located in Seri Iskandar, Perak which is have 3 cross road intersection. Equipment used in this study was DSLR camera and smart phone, which are used to record a video traffic data. The video was studied to count number of vehicle and be presented in form of table by using Microsoft Excel so that the trends of the concentration of carbon monoxide (CO) and carbon dioxide (CO_2) can be calculated by using SIDRA Intersection software.

4.2 Analysis of Traffic Count

Data sampling is taken from 7 am – 9 am and 4 pm – 6 pm every day for one whole week. Number of vehicle is collected, according to several classes with respect to time. From the collected data, peak hour can be identified by highest volume of vehicle in four consecutive 15-minute period. Analysis of traffic count is important in identify concentration of CO and CO_2 at the road intersection by using SIDRA Intersection analysis.

In the early assumption, Monday through Friday may have more or less the similar count of traffic. Traffic count were tabulated with respect to time. From the tabulated traffic data shown in Appendix 3 until Appendix 8, the highlighted data are the peak hour, where the highest volume of vehicle has been identified. For overall traffic count, total vehicle from Ipoh approach has the highest number of vehicle. Highest volume of vehicle from Ipoh approach was on Monday and Tuesday for morning and afternoon session respectively. From Lumut approach, the peak hour during morning and afternoon was on Thursday and Friday respectively. The peak hour from UTP approach was on Friday for both morning and afternoon period.

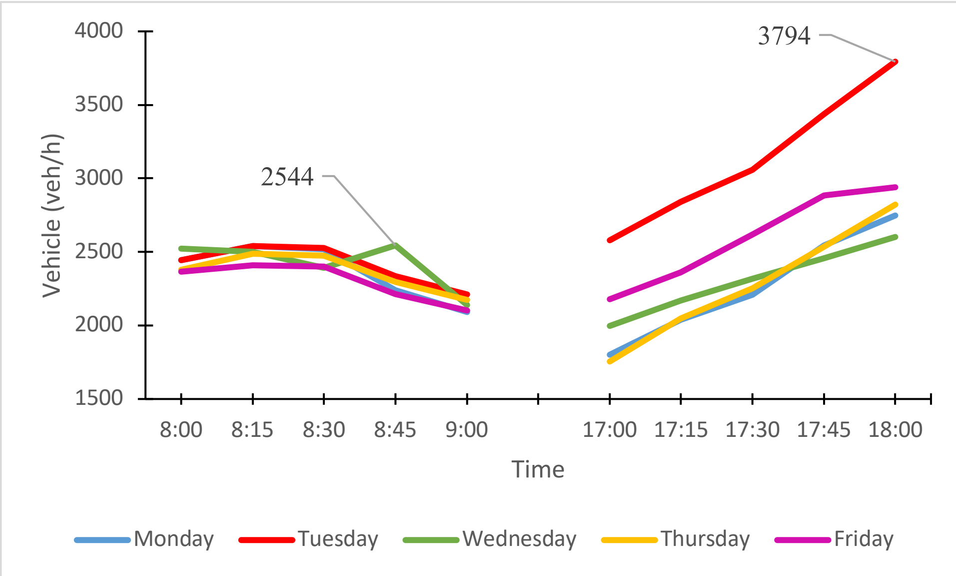

Figure 14: Number of vehicle respect to time on weekdays

Figure 14 shows the trend of vehicle during peak hour on weekdays, where highest number of vehicle recorded using the UTP intersection was on Tuesday afternoon with 3794 veh/h. The highest number of vehicle shows that most of the users are coming back from the work place in the late afternoon. In the morning peak hour, Wednesday recorded the highest number of vehicle (2544 veh/h) and this may reflect behaviour of the people going to work or school. In the morning peak hour, graph from Monday until Friday shows a quite similar trend which increasing from 8:00 am until 8:30 am then it starts decreasing until 9:00 am. The only different was recorded on Wednesday where there is sudden peak of number of vehicles on 8:45 am before it drops again. During afternoon peak hour, trends of vehicle through the intersection shows increasing from 5:00 pm until 6:00 pm. Wednesday and Thursday afternoon shows almost a linear graph throughout the sampling period.

Saturday and Sunday reading is expected to have less count of traffic compared to weekdays. Traffic count were tabulated with respect to time. From the tabulated traffic data in Appendix 7 and Appendix 8, the highlighted data are the peak hour, where the highest volume of vehicle has been identified. For overall traffic count during weekend, total vehicle from Lumut Approach has the highest number of vehicle.

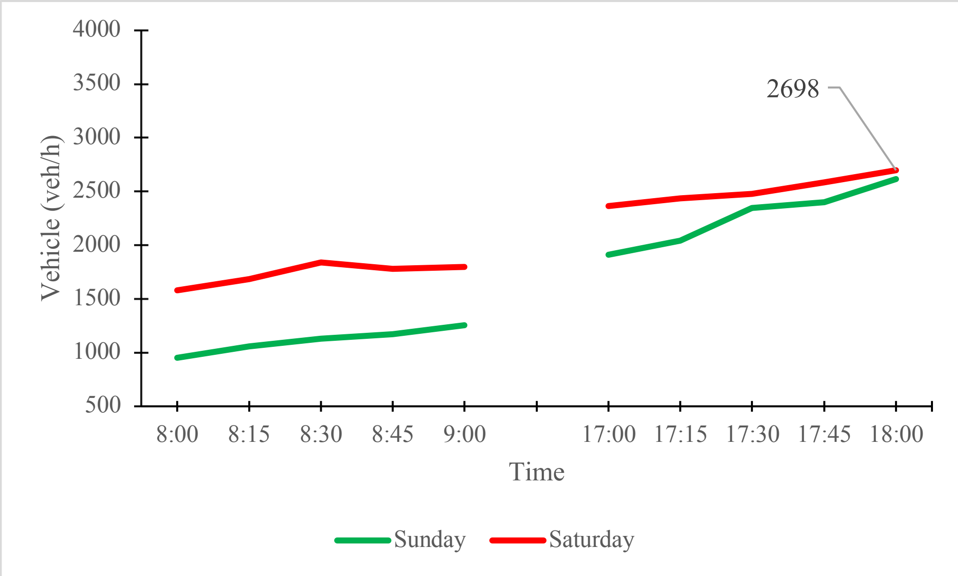

Figure 15: Volume of vehicle respective to time during weekend

Figure 15 shows the trend of vehicle during peak hour on weekend, where highest number of vehicle recorded using the UTP intersection was on Saturday afternoon with 2698 veh/h. Lowest number of vehicle recorded on Sunday morning with 952 veh/h at 8:00 am. On both morning and afternoon peak hour, number of vehicle keep on increasing on Sunday and Saturday respectively. On Saturday morning hour, there is peak number of vehicle at 8:30 am and drop to a constant number of vehicle until 9:00 am. During afternoon peak hour, number of vehicle going through the intersection was increasing from 5:00 pm to 5:30 pm, then constant until 5:45 pm before increasing again. Compare to Sunday reading, total number of vehicle on Saturday morning have more vehicles and this may because some people who still working on Saturday or people tend to go to wet market or having breakfast at the outside with all the family members. On both day, number of vehicle increase after 5:00 pm may because people tends to travel in late afternoon or most likely to do outdoor activity with family.

4.3 Concentration of Pollutants on Weekdays

Figure 16 shows the highest concentration of CO_2 recorded was on Tuesday afternoon with 962.6 kg/h corresponds to the highest number of vehicle recorded. If using that number and calculated in terms of day, the estimate carbon footprint is 23 tonnes CO_2e per day.

The highest concentration of CO calculated by SIDRA analysis was on Tuesday afternoon with concentration of 79.79 kg/h (Figure 17). Using that number to estimates CO for a day, it is about 1.9 tonnes of CO are released per day. In theory, air quality is affected by several factors including wind speed, rain and temperature (B.C. Air Quality, 2016).

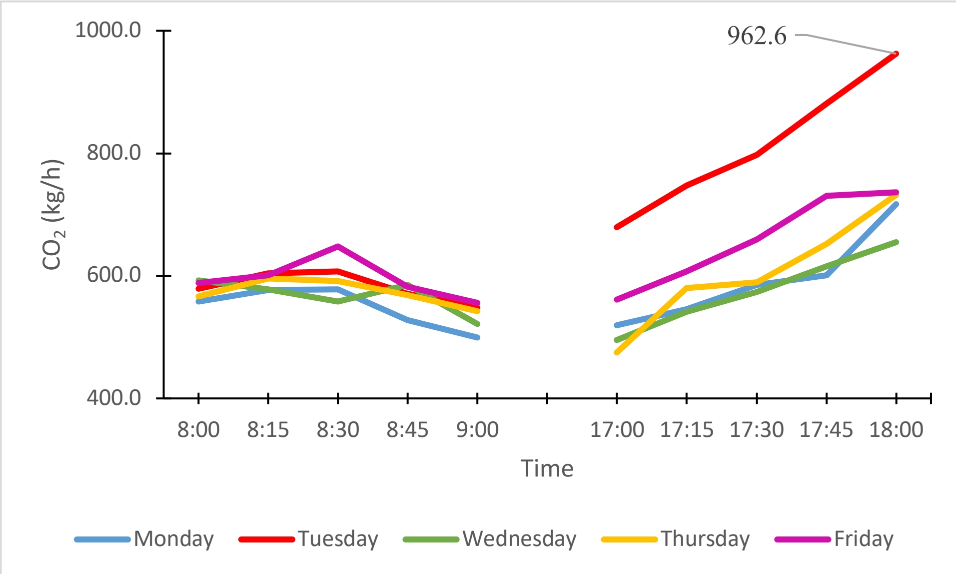

Figure 16: CO_2 emission respect to time during weekdays

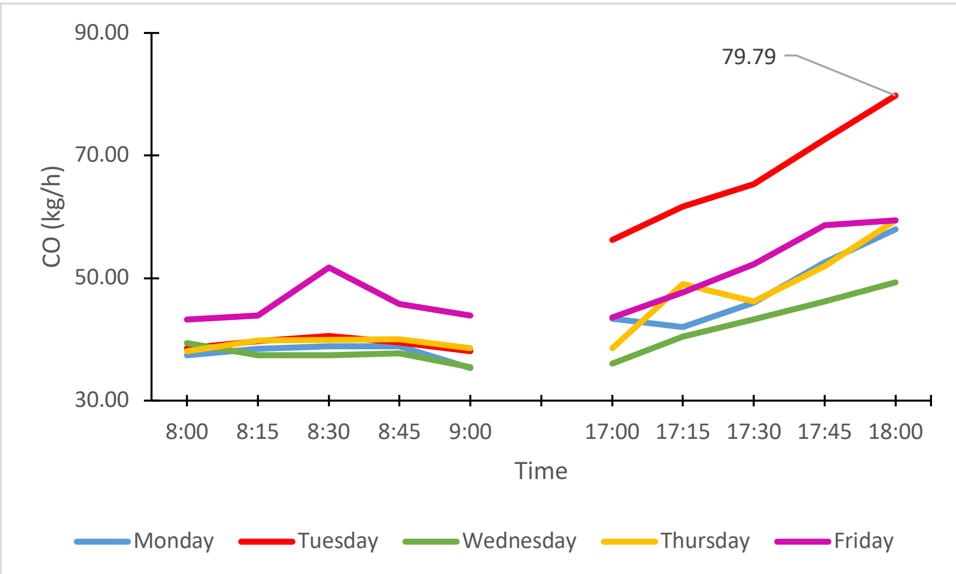

Figure 17: CO emission respect with time during weekdays

When the temperature is cooler especially at night, pollutants are not easily dispersed causing localised air pollutant. High temperature speeds up the chemical reaction in the atmosphere (Waikato, 2016). Meaning that pollutant concentrations reading during morning peak hour should be higher compared to afternoon but this case is not true for this study since SIDRA Intersection analysis did not considering temperature and time in the calculation.

Comparing both CO_2 and CO emission (Figure 16 and 16) and the number of vehicle, the concentration of CO and CO_2 are increasing as volume of vehicle increase. The emission trend for both CO and CO_2 are more or less the same but different in the concentration value. CO_2 emission concentration (Figure 16) are range from 475 kg/h up to 962.9 kg/h. CO pollutant concentrations (Figure 17) for study area a vary from 35 kg/h to 79.79 kg/h. The highest concentration of CO_2 and CO during morning peak hour was on Friday at 8.30 am with reading of 647.9 kg/h and 51.75 kg/h respectively.

Small value of CO concentration recorded as shown in Figure 18 and 18 shows that vehicles emit more CO_2 compared to CO because complete combustion engines took place. As shown in Graph 6 and 7, number of diesel vehicle or heavy vehicle (HV) using the intersection are small compared to number of light vehicle (LV).

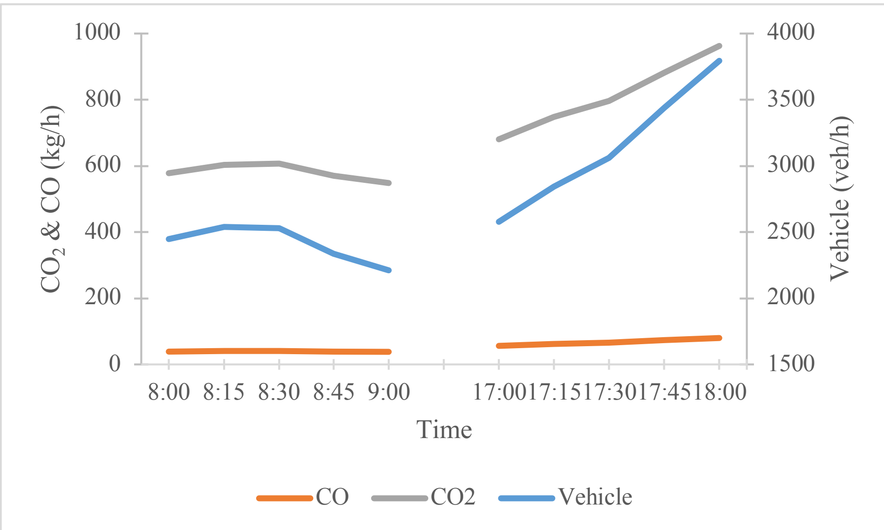

Figure 18: Relationship between CO_2 and CO concentration with vehicle number (Tuesday)

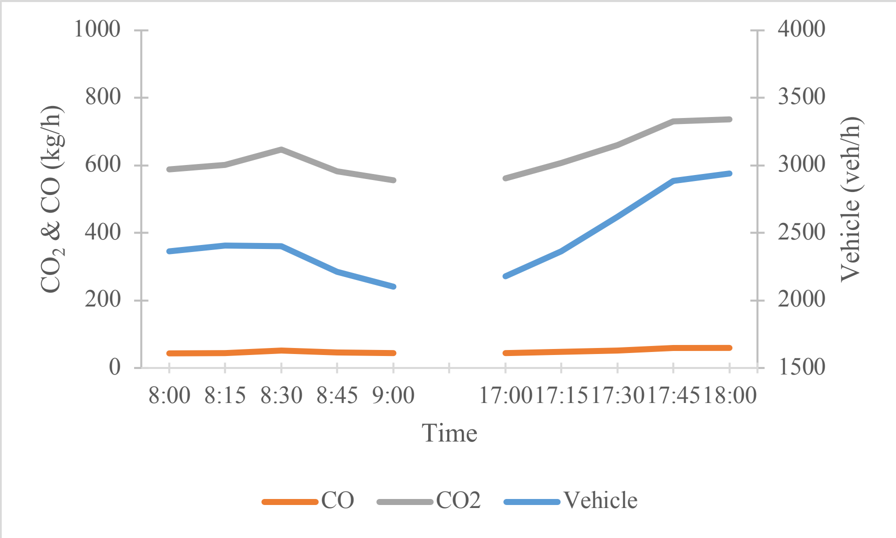

Figure 19: Relationship between CO_2 and CO concentration with vehicle number (Friday)

In Figure 18, number of vehicle did increase drastically after 5.30 pm but CO_2 concentration did not increase proportionally. This situation was explained in Figure 20 where decreasing volume of HV did control CO_2 emission even though volume of LV increase drastically. HV vehicle did contribute to concentration level of pollutant as shown in Figure 20 where volume HV increase during morning peak hour on Friday and affecting the CO and CO_2 concentration.

Comparing vehicles class and the emission concentration, both LV and HV give effect to concentration of CO and CO_2 but number of LV are more affecting the concentration of emission compare to HV as shown in Figure 20 and 20. Volume of LV that contributed to the emission concentration are vary from 1755 veh/h up to 3794 kg/h, which are bigger than volume HV that vary from 49 veh/h to 106 veh/h. Therefore, any changes in number of HV did not give major effect on concentration of CO_2 emission since very small percentage of HV compared to the number of LV using the intersection.

The graph of CO_2 in Figure 20 did decrease at 9:00am even the number of HV increase from 96 veh/h to 104 veh/h after 8:45am. Figure 20 shows concentration of CO_2 affected by reduction in number of LV, from 2240 veh/h to 2107 veh/h. Same situation are shown in Figure 21 where trend of CO_2 is following the number of LV.

Besides high number of LV, type of fuel used by these vehicles may contribute to the concentration of air pollutants. In Malaysia, RON 95 are mostly used by user for their vehicle as it is cheaper compare to RON 97. As price of petrol and diesel fuel controlled by Malaysian Government, RON 97 can be considered as a premium fuel for a normal car. Euro 4M RON 97, which is more clean and greener fuel also not available in all petrol station in Malaysia. Comparing RON 95 fuel and RON 97, most of the RON 97 fuel available in the market is Euro 4M grade fuel while RON 95 fuel is still Euro 2M grade fuel. Euro 4 fuel have strict acceptable emission limit and higher standard, which concerning sulphur content, benzene content and RVP levels (Ramajunam, 2016; Shah, 2016).

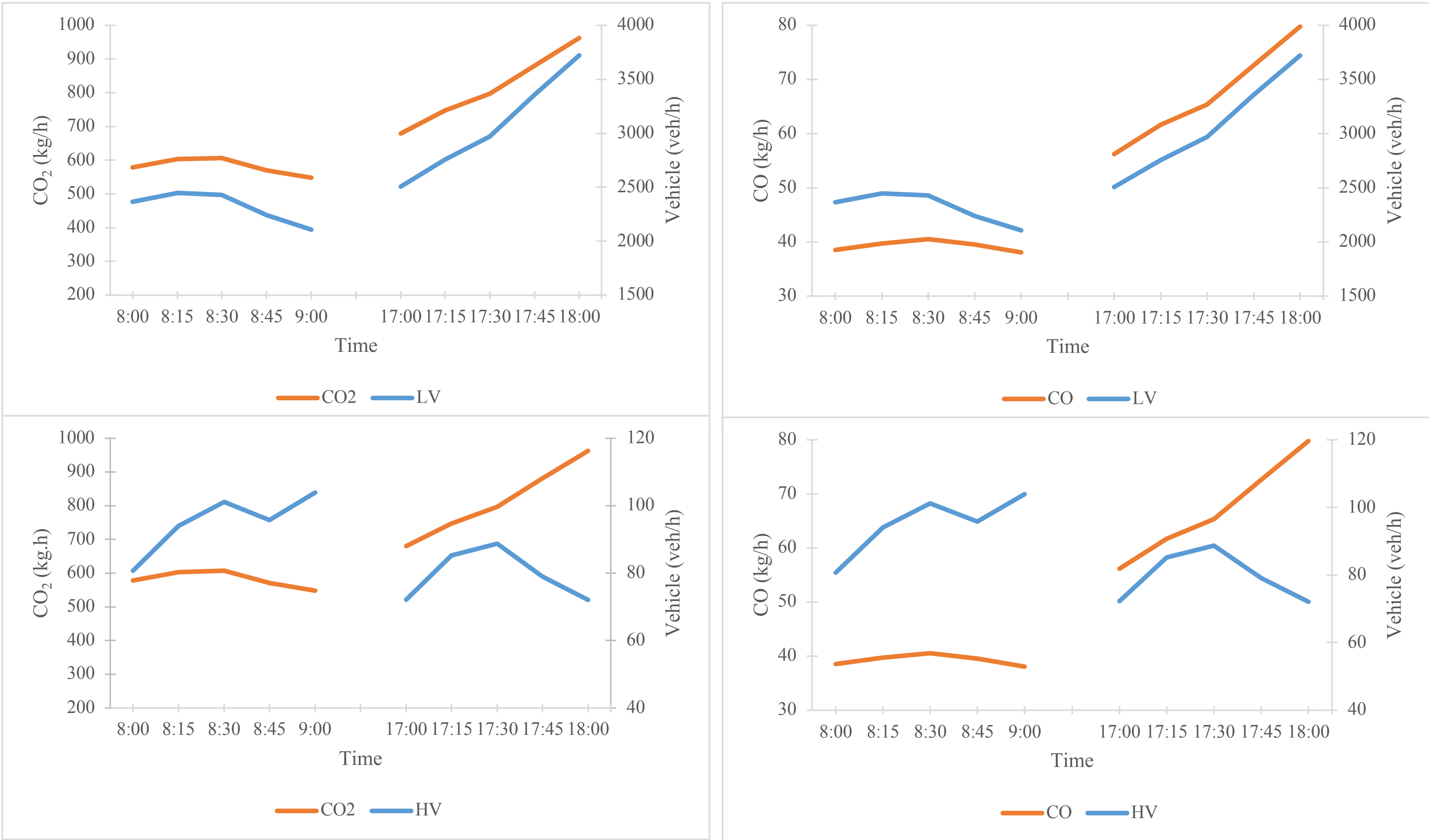

Figure 20: Relationship between CO_2 and CO concentration with volume LV and HV (Tuesday)

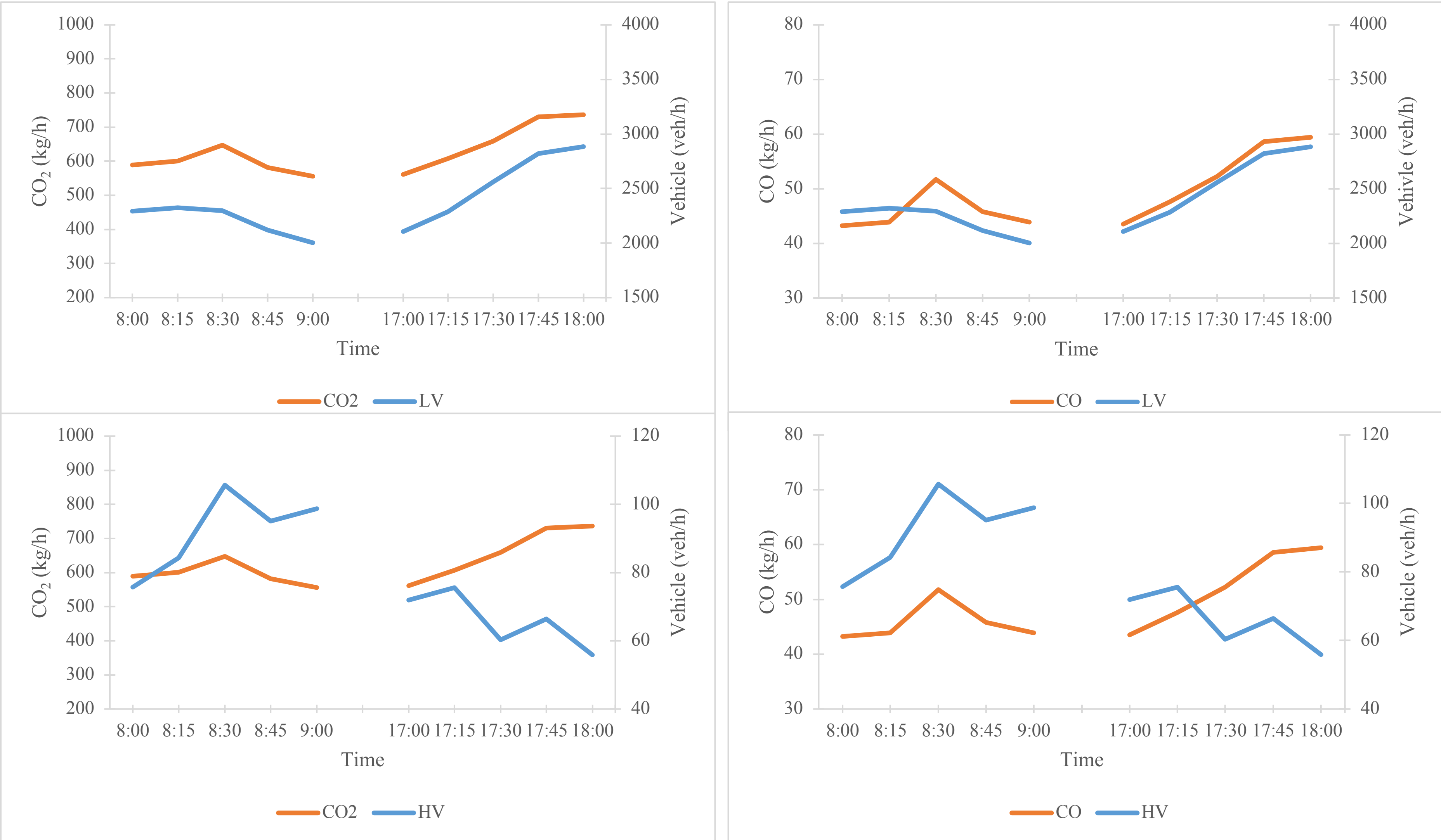

Figure 21: Relationship between CO_2 and CO concentration with volume of LV and HV (Friday)

4.4 Concentration of Pollutants on Weekend

As shown in Figure 22 and 23, the highest concentration of CO_2 and CO was 686 kg/h and 55.15 kg/h respectively. Using the highest value as a bechmark, esmission of CO_2 would be 16 tonnes per day while CO pollutant around 1.3 tonnes per day. Comparing to weekdays value, there is around 30 % reduction on CO_2 and CO emission during weekends.

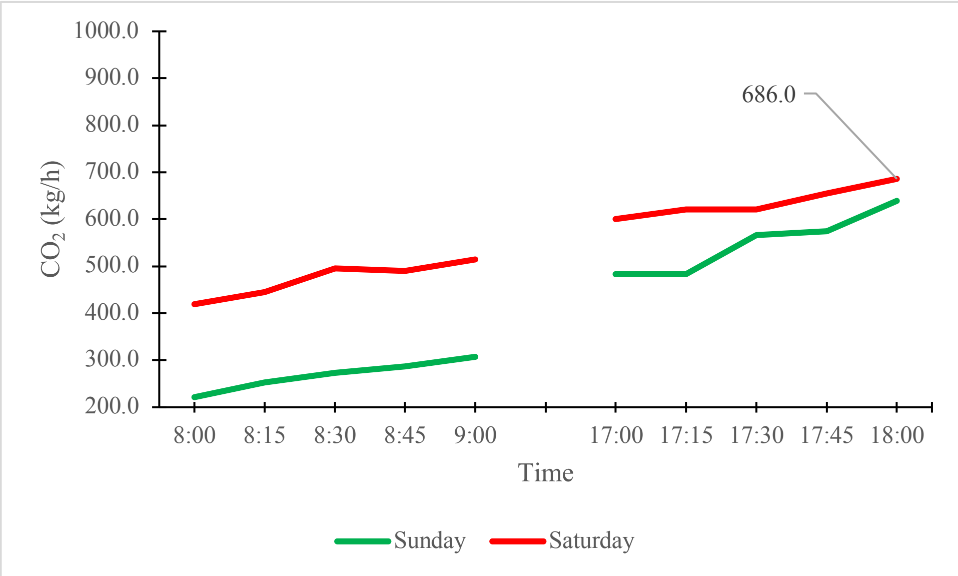

Figure 22: CO_2 emission respect to time during weekend

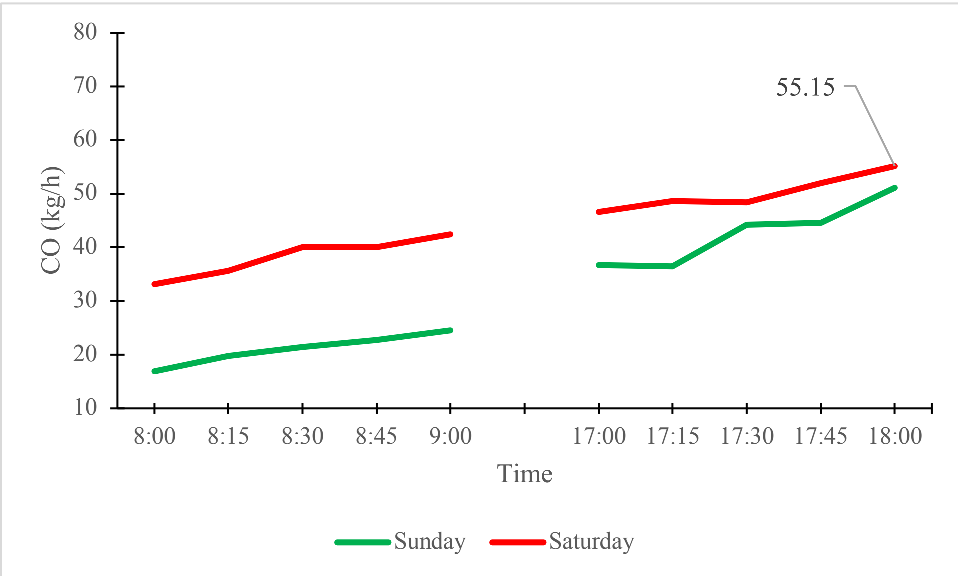

Figure 23: CO emission respect to time during weekend

Trend of CO_2 and CO emission (Figure 22 and 23) are more or less corresponding to the volume of vehicle using the intersection. In Figure 24, there was very least number of HV recorded on both Sunday morning and afternoon. Comparing vehicles class and the emission concentration, both LV and HV give effect to concentration of CO and CO_2 but number of LV are more affecting the concentration of CO and CO_2 compare to HV as shown in Graph 24 and 25. Any changes in number of HV did not give major effect on concentration of CO_2 emission since very small percentage of HV compared to the number of LV using the intersection.

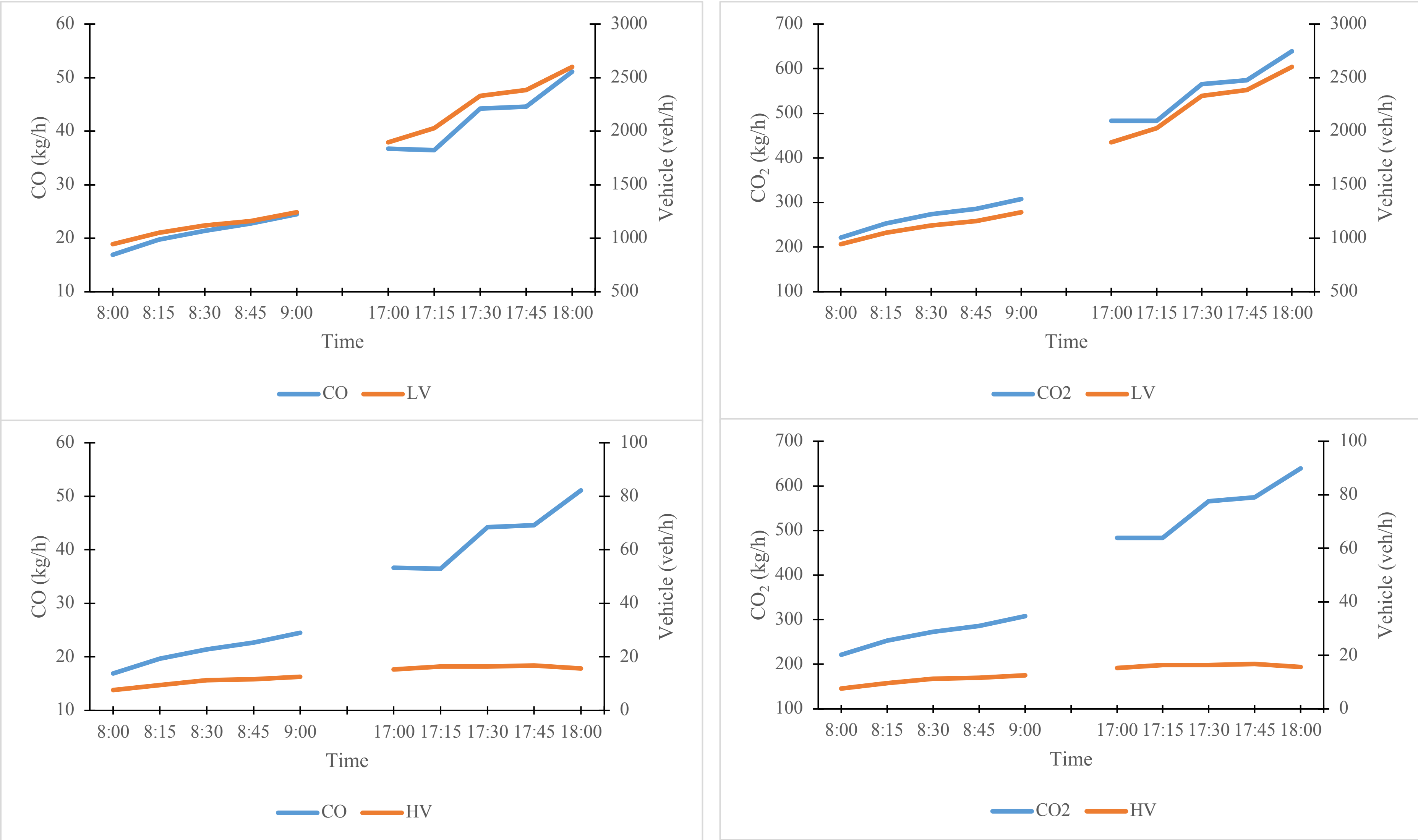

Figure 24: Relationship between CO_2 and CO concentration with volume of LV and HV (Sunday)

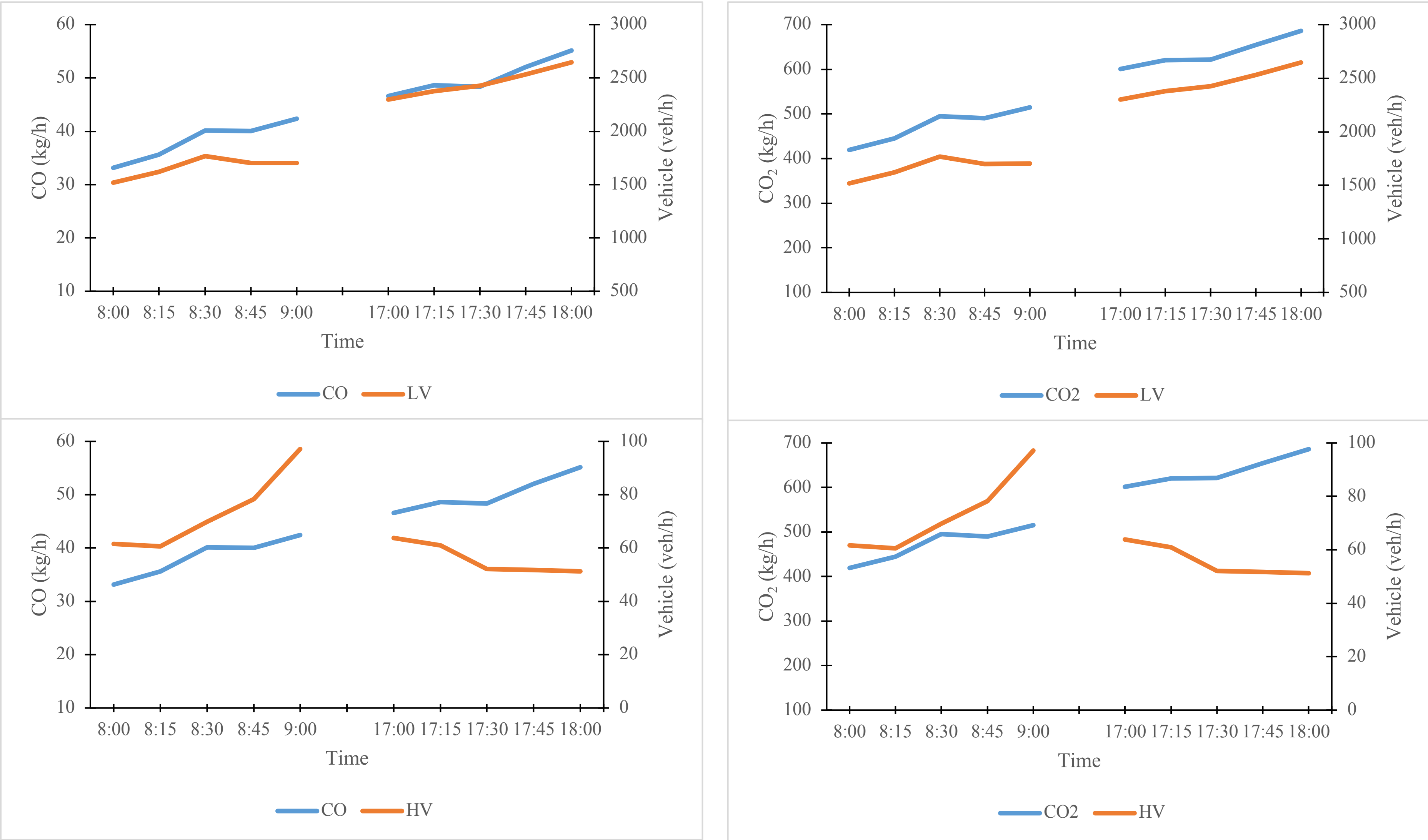

Figure 25: Relationship between CO_2 and CO concentration with volume of LV and HV (Saturday)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Pollutant gaseous from the idling vehicle at the traffic light intersection would be a serious matter as it contributes to the air pollution. Approaching the traffic light intersection or any road intersection, vehicle normally will experience four mode of driving for each driving cycle, namely cruise, acceleration, deceleration and idling. This study is important as pollutant from idling vehicle at the road intersection are likely give significant impact to the quality of air. Traffic data for this study was collected at UTP traffic light intersection for one week of sampling duration during morning and afternoon peak hour. This study has identified the concentration of carbon monoxide (CO) and carbon dioxide (CO_2) at the traffic light intersection from traffic count data by using SIDRA Intersection analysis. Results obtained shows that the concentration of CO and CO_2 are increasing as volume of vehicle increase. The highest concentration recorded at the UTP intersection was on Tuesday afternoon with CO and CO_2 recorded were 79.9 kg/h and 962.6 kg/h respectively. From this study, it shows that concentration of CO and CO_2 are affected mostly by light vehicle (LV) compared to heavy vehicle (HV). Number of vehicle and type of engines has been identified as factor of pollutant concentrations at the road intersection. Analysis of the results also would help to evaluate and predict the trend of air pollutants during peak hour at the study area. This study also should help the authority in deciding if any improvement to be done in the future to make the road intersection more effective and efficient. In conclusion, objectives of this study are achieved.

5.2 Recommendation

For study in the future, some recommendation can be included. Firstly, extension of the data sampling in terms of hours, which traffic data not only recorded during peak hour but for 12 hours or for the whole day. Extending the sampling period should give more reliable data and helps in knowing the trend of emission at the road intersection. Secondly, emission of pollutant can be calculated based on several types of vehicle. By doing this, emission for every type of vehicle such as motorcycles and busses can be known more details and specific. Lastly, measuring real emission concentration of pollutant at road intersection by using suitable equipment. There is several equipment available in the market that can be used to collect the real data of pollutant such as volatile organic compound (VOC), nitrogen dioxide (NO_x), sulphur dioxide (SO_2) and not limited to CO_2 only. By doing so, more pollutant data can be collected and more detail study can be conducted.

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APPENDICES

Appendix 1: Physical and chemical properties of carbon monoxide (Air Product, 2016)

Properties	Value
Molecular Weight (lb/mol)	28.01
Boiling Point (℃)	-191.5
Melting Point (℃)	-205.1
Specific Gravity	0.985
Critical Temperature (℃)	-140.2
Critical Pressure (kPa)	3348.09

Appendix 2: Physical and chemical properties of carbon dioxide (Air Product, 2016)

Properties	Value
Molecular Weight (lb/mol)	44.01
Boiling Point (℃)	-78.44
Melting Point (℃)	-56.61
Specific Gravity	1.555
Critical Temperature (℃)	31.06
Critical Pressure (kPa)	7384.285

Appendix 3: Data Sampling Results on Monday, 10 October 2016

IPOH APPROACH												
Time	**Towards**					**Right**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	125	15	7	1	40	14	0	0	0	17	219	
07:15 - 07:30	169	8	7	2	48	30	1	0	0	12	277	
07:30 - 07:45	237	19	10	2	60	69	2	0	0	14	413	
07:45 - 08:00	170	16	9	1	59	71	4	0	1	23	354	1263
08:00 - 08:15	128	30	18	1	36	97	2	0	0	14	326	1370
08:15 - 08:30	119	20	11	1	21	78	0	0	0	8	258	1351
08:30 - 08:45	97	27	11	1	18	67	1	0	0	2	224	1162
08:45 - 09:00	102	29	12	1	19	71	1	0	0	2	237	1045
16:00 - 16:15	94	26	10	1	13	11	1	0	0	4	160	
16:15 - 16:30	102	28	11	1	15	12	1	0	0	4	174	
16:30 - 16:45	119	26	10	2	25	17	1	0	0	5	205	
16:45 - 17:00	134	26	9	3	20	14	0	0	0	2	208	747
17:00 - 17:15	165	25	5	2	29	14	0	0	0	3	243	830
17:15 - 17:30	145	24	6	0	27	24	0	0	0	0	226	882
17:30 - 17:45	192	22	2	2	44	18	0	0	0	2	282	959
17:45 - 18:00	189	23	7	3	36	16	0	0	0	3	277	1028
LUMUT APPROACH												
Time	**Towards**					**Left**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	207	4	8	2	32	11	1	0	0	6	271	
07:15 - 07:30	155	11	0	0	51	14	0	0	0	8	239	
07:30 - 07:45	217	10	3	2	45	29	0	0	0	3	309	
07:45 - 08:00	139	11	2	1	41	22	0	0	0	7	223	1042
08:00 - 08:15	139	18	5	3	42	39	1	0	0	6	253	1024
08:15 - 08:30	127	19	4	1	27	40	1	0	0	3	222	1007
08:30 - 08:45	128	25	3	1	29	27	1	0	0	6	220	918
08:45 - 09:00	96	19	2	1	28	26	1	0	0	6	179	874
16:00 - 16:15	103	27	9	3	18	15	0	0	0	3	178	
16:15 - 16:30	120	32	11	4	21	13	0	0	0	3	204	
16:30 - 16:45	117	35	13	0	26	24	1	0	0	2	218	
16:45 - 17:00	159	35	8	1	28	21	0	0	0	3	255	855
17:00 - 17:15	141	30	18	0	58	9	2	0	0	5	263	940
17:15 - 17:30	168	21	11	2	35	16	0	0	0	10	263	999
17:30 - 17:45	211	21	12	4	30	32	0	0	0	4	314	1095
17:45 - 18:00	176	25	11	0	37	27	0	0	1	6	283	1123
UTP APPROACH												
Time	**Right**					**Left**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	6	1	0	0	1	5	0	0	0	0	13	

07:15 - 07:30	7	0	0	0	0	3	0	0	0	2	12	
07:30 - 07:45	8	0	0	1	0	12	1	0	0	1	23	
07:45 - 08:00	5	0	0	0	2	6	1	0	0	2	16	64
08:00 - 08:15	8	1	0	0	6	4	0	0	0	1	20	71
08:15 - 08:30	10	1	0	0	5	12	2	0	0	6	36	95
08:30 - 08:45	16	2	0	0	2	15	0	0	0	3	38	110
08:45 - 09:00	19	2	0	0	2	13	0	0	0	3	39	133
16:00 - 16:15	18	1	0	0	5	10	1	0	0	0	35	
16:15 - 16:30	24	1	0	0	7	13	1	0	0	0	46	
16:30 - 16:45	23	1	0	0	10	20	0	0	0	0	54	
16:45 - 17:00	22	1	0	0	4	28	0	0	0	0	55	190
17:00 - 17:15	52	1	0	0	4	39	3	0	0	0	99	254
17:15 - 17:30	70	1	0	0	16	51	2	0	0	1	141	349
17:30 - 17:45	53	0	0	0	22	57	0	0	0	8	140	435
17:45 - 18:00	74	0	0	0	9	65	0	0	0	5	153	533

Appendix 4: Data Sampling Results on Tuesday, 11 October 2016

IPOH APPROACH												
Time	**Towards**					**Right**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	101	10	10	1	36	29	0	0	0	16	203	
07:15 - 07:30	159	14	14	2	50	39	0	0	0	22	300	
07:30 - 07:45	180	17	21	1	58	83	3	0	0	17	380	
07:45 - 08:00	203	26	10	1	57	54	2	0	0	10	363	1246
08:00 - 08:15	127	18	23	0	27	87	3	0	0	13	298	1341
08:15 - 08:30	138	18	10	2	27	93	0	0	0	11	299	1340
08:30 - 08:45	101	22	14	0	21	86	3	0	0	10	257	1217
08:45 - 09:00	140	33	14	4	23	76	7	0	0	6	303	1157
16:00 - 16:15	126	21	11	1	8	20	2	0	0	3	192	
16:15 - 16:30	125	22	7	1	14	8	2	0	0	6	185	
16:30 - 16:45	113	26	6	4	24	6	1	0	0	1	181	
16:45 - 17:00	134	27	8	1	17	13	1	0	0	1	202	760
17:00 - 17:15	110	15	12	1	22	10	0	0	0	4	174	742
17:15 - 17:30	172	25	12	1	34	23	4	0	0	4	275	832
17:30 - 17:45	161	52	6	3	36	18	2	0	0	4	282	933
17:45 - 18:00	194	53	1	3	30	16	3	0	0	3	303	1034
LUMUT APPROACH												
Time	**Towards**					**Left**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	163	9	9	2	34	10	0	0	0	3	230	
07:15 - 07:30	160	8	4	1	45	14	0	0	0	9	241	
07:30 - 07:45	167	8	4	1	37	21	0	0	0	12	250	
07:45 - 08:00	153	18	4	2	50	43	1	0	0	10	281	1002

08:00 - 08:15	131	21	10	0	24	37	1	0	0	5	229	1001
08:15 - 08:30	111	22	15	3	10	45	0	0	1	5	212	972
08:30 - 08:45	110	11	6	0	17	25	0	0	0	3	172	894
08:45 - 09:00	98	32	11	1	18	50	1	0	0	13	224	837
16:00 - 16:15	107	29	4	1	12	27	1	0	0	4	185	
16:15 - 16:30	128	33	7	2	11	7	0	0	1	4	193	
16:30 - 16:45	100	23	16	2	17	19	0	0	0	2	179	
16:45 - 17:00	159	44	10	0	34	21	0	0	0	4	272	829
17:00 - 17:15	152	30	14	1	57	30	0	0	0	5	289	933
17:15 - 17:30	157	13	5	1	30	17	0	0	0	6	229	969
17:30 - 17:45	164	25	8	2	23	29	0	0	0	6	257	1047
17:45 - 18:00	216	23	9	0	56	35	0	1	0	6	346	1121

UTP APPROACH

Time	Right					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	7	0	0	0	2	6	0	0	0	4	19.00	
07:15 - 07:30	6	0	0	0	0	2	0	0	0	3	11.00	
07:30 - 07:45	6	2	0	0	1	5	0	0	0	1	15.00	
07:45 - 08:00	14	0	0	0	8	6	2	0	0	0	30.00	75
08:00 - 08:15	7	1	0	0	1	7	0	0	0	0	16.00	72
08:15 - 08:30	7	1	0	0	1	12	0	0	0	9	30.00	91
08:30 - 08:45	17	0	0	0	0	9	1	0	0	5	32.00	108
08:45 - 09:00	12	0	0	0	3	11	1	0	0	1	28.00	106
16:00 - 16:15	33	0	0	0	6	11	1	0	0	12	63	
16:15 - 16:30	30	0	0	0	12	19	1	0	0	8	70	
16:30 - 16:45	21	0	0	0	7	15	0	0	0	18	61	
16:45 - 17:00	25	0	0	0	7	15	2	0	0	6	55	249
17:00 - 17:15	60	3	0	0	9	61	0	0	0	6	139	325
17:15 - 17:30	68	0	0	0	20	37	0	1	0	8	134	389
17:30 - 17:45	79	0	0	0	17	73	2	0	0	12	183	511
17:45 - 18:00	93	1	0	0	10	63	1	1	0	9	178	634

Appendix 5: Data Sampling Results on Thursday, 13 October 2016

IPOH APPROACH

Time	Towards					Right					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	108	10	9	1	36	28	0	0	0	16	208	
07:15 - 07:30	152	14	13	2	50	39	0	0	0	22	292	
07:30 - 07:45	203	26	12	1	57	54	2	0	0	10	365	
07:45 - 08:00	177	17	20	1	58	83	3	0	0	17	376	1241
08:00 - 08:15	127	18	23	0	29	87	3	0	0	13	300	1333
08:15 - 08:30	134	18	10	2	26	91	0	0	0	11	292	1333

08:30 - 08:45	101	22	14	0	19	86	3	0	0	7	252	1220
08:45 - 09:00	140	33	14	4	23	74	7	0	0	6	301	1145
16:00 - 16:15	92	31	5	1	12	18	2	0	0	3	164	
16:15 - 16:30	113	23	7	1	17	7	5	0	0	2	175	
16:30 - 16:45	124	31	8	4	25	7	2	0	0	3	204	
16:45 - 17:00	132	30	6	1	24	14	1	0	0	1	209	752
17:00 - 17:15	121	14	9	3	20	22	1	0	0	4	194	782
17:15 - 17:30	155	23	7	1	31	9	1	0	0	4	231	838
17:30 - 17:45	177	47	9	1	40	14	0	0	0	4	292	926
17:45 - 18:00	198	40	11	1	27	15	3	0	0	3	298	1015

LUMUT APPROACH

Time	Towards					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	160	10	6	1	44	8	1	0	0	2	232	
07:15 - 07:30	154	10	6	1	59	10	1	0	0	3	244	
07:30 - 07:45	159	19	6	3	46	28	1	0	0	12	274	
07:45 - 08:00	142	17	4	2	59	50	1	0	0	9	284	1034
08:00 - 08:15	142	7	5	0	31	53	1	0	0	4	243	1045
08:15 - 08:30	121	19	9	0	28	44	1	0	0	5	227	1028
08:30 - 08:45	103	20	14	3	12	53	0	0	1	5	211	965
08:45 - 09:00	91	30	10	1	21	59	1	0	0	12	225	906
16:00 - 16:15	100	27	4	1	11	17	1	0	0	4	165	
16:15 - 16:30	119	31	7	2	10	20	0	0	1	5	195	
16:30 - 16:45	107	25	17	2	19	17	0	0	0	2	189	
16:45 - 17:00	170	37	11	1	37	24	0	0	0	4	284	833
17:00 - 17:15	141	28	13	1	40	28	0	0	0	5	256	924
17:15 - 17:30	173	14	6	1	40	15	0	0	0	6	255	984
17:30 - 17:45	153	23	5	1	39	31	0	0	0	3	255	1050
17:45 - 18:00	231	25	10	1	34	37	0	0	0	3	341	1107

UTP APPROACH

Time	Right					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	7	0	0	0	1	6	0	0	0	4	18	
07:15 - 07:30	6	0	0	0	1	5	0	0	0	3	15	
07:30 - 07:45	4	1	0	1	2	5	1	0	0	2	16	
07:45 - 08:00	6	0	0	0	1	3	0	0	0	1	11	60
08:00 - 08:15	13	1	0	0	8	6	2	0	0	3	33	75
08:15 - 08:30	7	1	0	0	1	7	0	0	0	4	20	80
08:30 - 08:45	17	0	0	0	0	12	0	0	1	1	31	95
08:45 - 09:00	12	0	0	0	3	13	1	0	0	1	30	114
16:00 - 16:15	31	0	0	0	6	10	1	0	0	11	59	
16:15 - 16:30	28	1	0	0	11	18	1	0	0	9	68	
16:30 - 16:45	22	0	0	0	7	16	0	0	0	17	62	
16:45 - 17:00	27	0	0	0	7	16	2	0	0	7	59	248

17:00 - 17:15	56	1	0	0	8	57	0	0	0	7	129	318
17:15 - 17:30	75	0	0	0	18	41	0	0	0	9	143	393
17:30 - 17:45	73	0	0	0	16	68	2	0	0	10	169	500
17:45 - 18:00	100	1	0	0	11	67	1	0	0	8	188	629

Appendix 6: Data Sampling Results on Friday, 14 October 2016

IPOH APPROACH

Time	Towards					Right					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	103	12	12	1	33	15	2	0	0	22	200	
07:15 - 07:30	169	20	8	2	52	36	4	0	0	17	308	
07:30 - 07:45	186	18	21	0	55	45	3	0	0	12	340	
07:45 - 08:00	191	22	9	4	70	68	1	0	1	14	380	1228
08:00 - 08:15	129	21	19	1	35	70	3	0	0	15	293	1321
08:15 - 08:30	134	27	15	0	42	98	1	0	0	11	328	1341
08:30 - 08:45	94	20	13	0	9	76	3	0	0	5	220	1221
08:45 - 09:00	112	26	11	2	30	69	3	0	0	6	259	1100
16:00 - 16:15	138	31	11	2	12	21	3	0	0	2	220	
16:15 - 16:30	133	28	8	1	10	19	2	0	0	2	203	
16:30 - 16:45	115	26	6	1	18	11	3	0	0	1	181	
16:45 - 17:00	144	34	7	2	21	13	1	0	0	1	223	827
17:00 - 17:15	167	25	11	2	21	21	1	0	0	1	249	856
17:15 - 17:30	194	33	2	3	25	22	1	0	0	4	284	937
17:30 - 17:45	178	20	8	1	41	18	0	0	0	3	269	1025
17:45 - 18:00	152	17	2	0	32	17	0	0	0	2	220	1022

LUMUT APPROACH

Time	Towards					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	168	10	6	1	38	12	0	0	0	4	239	
07:15 - 07:30	175	14	6	0	61	19	2	0	0	5	282	
07:30 - 07:45	164	17	5	0	43	31	0	0	0	12	272	
07:45 - 08:00	144	19	5	1	35	35	0	0	0	5	244	1037
08:00 - 08:15	100	10	8	0	27	28	2	0	0	3	178	976
08:15 - 08:30	135	25	18	0	25	48	1	0	0	4	256	950
08:30 - 08:45	85	22	4	2	16	43	1	0	0	9	182	860
08:45 - 09:00	102	28	6	1	10	76	0	0	0	8	231	847
16:00 - 16:15	155	44	6	2	19	25	0	0	0	5	256	
16:15 - 16:30	161	32	18	2	16	29	0	0	0	7	265	
16:30 - 16:45	111	29	4	0	27	26	0	0	0	6	203	
16:45 - 17:00	184	33	9	0	27	24	0	0	0	4	281	1005
17:00 - 17:15	205	35	8	2	39	30	0	0	0	3	322	1071
17:15 - 17:30	203	28	11	2	43	26	0	0	0	8	321	1127
17:30 - 17:45	170	18	7	4	35	28	0	0	0	9	271	1195

17:45 - 18:00	154	32	3	2	28	20	0	2	0	3	244	1158

UTP APPROACH

Time	Right					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	4	0	0	0	2	4	0	0	0	3	13	
07:15 - 07:30	7	1	0	1	0	6	0	0	0	3	18	
07:30 - 07:45	3	0	0	0	1	5	1	0	0	1	11	
07:45 - 08:00	6	1	0	0	1	5	0	0	0	0	13	55
08:00 - 08:15	21	1	0	0	1	7	0	0	0	0	30	72
08:15 - 08:30	14	1	0	0	6	9	1	0	0	5	36	90
08:30 - 08:45	10	0	0	0	5	16	0	0	0	2	33	112
08:45 - 09:00	15	0	0	0	1	14	3	0	0	2	35	134
16:00 - 16:15	26	0	0	0	5	20	0	0	0	4	55	
16:15 - 16:30	37	1	0	0	11	31	1	0	0	8	89	
16:30 - 16:45	17	0	0	0	16	33	1	0	0	17	84	
16:45 - 17:00	33	1	0	0	9	28	2	0	0	7	80	308
17:00 - 17:15	51	1	0	0	8	66	1	0	0	7	134	387
17:15 - 17:30	83	2	0	0	17	72	1	0	1	9	185	483
17:30 - 17:45	73	1	0	0	12	95	1	0	0	4	186	585
17:45 - 18:00	73	2	0	0	8	72	0	0	0	5	160	665

Appendix 7: Data Sampling Results on Saturday, 15 October 2016

IPOH APPROACH

Time	Towards					Right					Total	Peak Hour
	1	2 & 3	4	5	6	1	2&3	4	5	6		
07:00 - 07:15	74	17	16	1	35	7	0	0	0	17	167	
07:15 - 07:30	69	10	4	1	30	16	1	0	0	17	148	
07:30 - 07:45	95	18	11	1	35	27	0	0	0	9	196	
07:45 - 08:00	99	16	8	2	34	23	1	0	0	15	198	709
08:00 - 08:15	103	13	12	2	32	27	1	0	0	8	198	740
08:15 - 08:30	104	23	12	0	28	25	1	0	0	8	201	793
08:30 - 08:45	66	17	10	1	13	27	1	0	0	4	139	736
08:45 - 09:00	121	25	15	2	27	21	4	0	0	4	219	757
16:00 - 16:15	156	27	7	2	29	20	1	0	0	3	245	
16:15 - 16:30	195	31	9	2	15	23	1	0	1	1	278	
16:30 - 16:45	166	21	8	2	18	11	0	0	0	4	230	
16:45 - 17:00	156	18	3	1	15	18	2	0	0	1	214	967
17:00 - 17:15	175	27	4	1	29	20	1	0	0	1	258	980
17:15 - 17:30	238	20	9	1	28	23	2	0	0	1	322	1024
17:30 - 17:45	135	33	5	2	29	24	1	0	2	7	238	1032
17:45 - 18:00	128	31	5	2	28	23	1	0	0	7	225	1043

LUMUT APPROACH												
Time	**Towards**					**Left**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	90	23	3	1	25	5	1	0	0	3	151	
07:15 - 07:30	82	7	8	2	16	12	0	0	0	10	137	
07:30 - 07:45	148	13	4	3	37	17	0	0	0	3	225	
07:45 - 08:00	122	10	4	2	27	24	1	0	0	2	192	705
08:00 - 08:15	103	23	7	3	21	23	1	0	0	3	184	738
08:15 - 08:30	135	15	9	2	21	24	0	0	0	6	212	813
08:30 - 08:45	140	20	12	0	14	22	1	0	0	2	211	799
08:45 - 09:00	109	15	15	2	25	21	2	0	0	1	190	797
16:00 - 16:15	185	28	11	1	23	26	1	0	0	6	281	
16:15 - 16:30	188	29	9	2	33	28	1	0	0	8	298	
16:30 - 16:45	136	26	4	1	30	17	0	0	0	7	221	
16:45 - 17:00	174	36	9	3	24	24	1	0	0	7	278	1078
17:00 - 17:15	198	36	6	1	47	34	2	0	0	3	327	1124
17:15 - 17:30	208	25	6	2	28	19	1	0	0	2	291	1117
17:30 - 17:45	203	31	6	4	28	38	0	0	0	6	316	1212
17:45 - 18:00	225	34	7	4	31	42	0	0	0	7	350	1284
UTP APPROACH												
Time	**Right**					**Left**					**Total**	**Peak Hour**
	1	**2 & 3**	**4**	**5**	**6**	**1**	**2 & 3**	**4**	**5**	**6**		
07:00 - 07:15	3	1	0	0	1	2	1	0	0	1	9	
07:15 - 07:30	4	0	0	2	2	8	0	0	0	3	19	
07:30 - 07:45	6	0	0	0	4	9	0	0	0	4	23	
07:45 - 08:00	15	1	0	0	0	18	0	0	0	2	36	87
08:00 - 08:15	15	0	0	0	7	13	1	0	0	6	42	120
08:15 - 08:30	15	1	0	0	2	13	2	0	0	5	38	139
08:30 - 08:45	19	1	0	0	3	15	0	0	0	1	39	155
08:45 - 09:00	12	3	0	0	7	13	0	0	0	1	36	155
16:00 - 16:15	25	0	0	0	4	16	2	0	0	5	52	
16:15 - 16:30	18	1	0	0	4	22	0	0	0	0	45	
16:30 - 16:45	22	1	0	0	2	20	4	0	0	18	67	
16:45 - 17:00	15	0	0	0	5	13	1	0	0	2	36	200
17:00 - 17:15	23	1	0	0	6	21	1	0	0	7	59	207
17:15 - 17:30	27	0	0	0	4	18	2	0	0	1	52	214
17:30 - 17:45	21	1	0	0	4	31	1	0	0	6	64	211
17:45 - 18:00	20	1	0	0	4	29	1	0	0	6	61	236

Appendix 8: Data Sampling Results on Sunday, 9 October 2016

IPOH APPROACH												
Time	Towards					Right					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	37	6	3	1	20	16	0	0	0	7	90	
07:15 - 07:30	57	7	1	2	25	9	2	0	1	2	106	
07:30 - 07:45	60	5	1	2	24	19	4	0	0	8	123	
07:45 - 08:00	75	10	0	1	18	8	0	0	0	3	115	434
08:00 - 08:15	75	8	2	2	21	9	0	0	0	0	117	461
08:15 - 08:30	106	5	2	1	13	4	0	0	0	3	134	489
08:30 - 08:45	68	14	1	1	11	13	1	0	0	1	110	476
08:45 - 09:00	96	20	1	3	23	10	1	0	0	0	154	515
16:00 - 16:15	155	17	2	3	10	16	1	0	1	1	206	
16:15 - 16:30	155	8	4	5	17	15	1	0	0	1	206	
16:30 - 16:45	183	13	1	0	16	17	1	0	0	1	232	
16:45 - 17:00	150	11	2	2	9	14	0	0	0	1	189	833
17:00 - 17:15	170	20	3	0	20	23	0	0	0	0	236	863
17:15 - 17:30	220	16	4	1	16	24	1	0	0	0	282	939
17:30 - 17:45	217	14	3	1	21	27	1	0	0	2	286	993
17:45 - 18:00	190	14	0	4	21	10	0	0	0	2	241	1045
LUMUT APPROACH												
Time	Towards					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	55	6	0	2	9	9	0	0	0	3	84	
07:15 - 07:30	62	7	0	1	16	22	0	0	0	7	115	
07:30 - 07:45	53	2	1	1	11	16	0	0	1	5	90	
07:45 - 08:00	94	4	1	2	14	10	0	0	0	0	125	414
08:00 - 08:15	117	5	3	0	12	10	0	0	0	1	148	478
08:15 - 08:30	113	1	1	1	14	10	0	0	0	2	142	505
08:30 - 08:45	83	4	1	1	10	13	0	0	0	1	113	528
08:45 - 09:00	109	8	1	1	21	10	0	0	0	0	150	553
16:00 - 16:15	177	20	0	1	14	14	0	0	0	6	232	
16:15 - 16:30	91	8	0	0	18	12	1	0	0	1	131	
16:30 - 16:45	234	25	5	2	24	31	0	0	0	3	324	
16:45 - 17:00	152	8	1	2	9	10	0	0	0	1	183	870
17:00 - 17:15	242	12	0	4	22	29	1	0	0	9	319	957
17:15 - 17:30	230	17	0	2	20	30	0	0	0	4	303	1129
17:30 - 17:45	234	20	2	3	19	30	0	0	0	6	314	1119
17:45 - 18:00	248	25	2	1	21	28	0	0	0	1	326	1262

UTP APPROACH												
Time	Right					Left					Total	Peak Hour
	1	2 & 3	4	5	6	1	2 & 3	4	5	6		
07:00 - 07:15	5	0	0	0	0	4	0	0	0	0	9	
07:15 - 07:30	4	0	0	0	0	9	0	0	0	0	13	
07:30 - 07:45	7	0	0	0	0	4	0	0	0	0	11	
07:45 - 08:00	9	0	0	0	1	10	2	0	1	0	23	56
08:00 - 08:15	12	0	0	0	1	9	0	0	0	0	22	69
08:15 - 08:30	11	0	0	1	3	8	0	0	0	0	23	79
08:30 - 08:45	20	0	0	0	4	17	0	0	0	0	41	109
08:45 - 09:00	17	0	0	0	7	12	1	0	0	0	37	123
16:00 - 16:15	16	0	0	0	4	14	0	0	0	2	36	
16:15 - 16:30	3	0	0	0	0	6	0	0	0	0	9	
16:30 - 16:45	16	0	0	0	3	19	0	0	0	2	40	
16:45 - 17:00	13	0	0	0	5	5	0	0	0	3	26	111
17:00 - 17:15	24	1	0	0	1	17	1	0	0	4	48	123
17:15 - 17:30	21	0	0	0	9	15	1	0	0	2	48	162
17:30 - 17:45	22	0	0	0	7	12	1	0	0	3	45	167
17:45 - 18:00	20	0	0	0	3	13	0	0	0	1	37	178

Appendix 9: Volume of Vehicle (veh/h) for a week of data sampling

Time	Sun	Mon	Tue	Wed	Thu	Fri	Sat
7:00-8:00	952	2445	2445	2522	2378	2366	1580
7:15-8:15	1061	2538	2541	2502	2488	2408	1682
7:30-8:30	1129	2518	2529	2391	2476	2401	1837
7:45-8:45	1172	2239	2336	2544	2296	2213	1779
8:00-9:00	1254	2091	2211	2140	2175	2102	1799
16:00-17:00	1909	1801	2579	1997	1755	2180	2636
16:15-17:15	2045	2041	2842	2169	2048	2362	2438
16:30-17:30	2347	2211	3059	2318	2251	2620	2479
16:45-17:45	2399	2545	3437	2458	2537	2886	2584
17:00-18:00	2616	2748	3794	2602	2822	2940	2698

Appendix 10: CO_2 concentration (kg/h) from SIDRA Intersection analysis

Time	Sun	Mon	Tue	Wed	Thu	Fri	Sat
7:00-8:00	221.4	557.6	578.6	592.5	566.3	588.5	419.3
7:15-8:15	253.0	577.2	603.6	578.3	595.3	600.6	445.0
7:30-8:30	273.3	578.1	606.8	558.2	591.5	647.9	495.3
7:45-8:45	286.2	527.8	570.3	585.1	569.0	581.9	490.2
8:00-9:00	307.8	499.4	548.2	522.0	542.4	556.0	514.8
16:00-17:00	483.3	519.0	679.8	495.3	475.0	561.6	601.0
16:15-17:15	483.4	545.9	747.1	541.2	579.7	607.4	620.5
16:30-17:30	565.8	585.8	797.2	574.2	589.8	659.4	621.0
16:45-17:45	574.4	600.9	881.0	615.4	652.3	730.9	654.5
17:00-18:00	639.2	717.0	962.6	655.0	732.2	736.4	686.0

Appendix 11: CO concentration (kg/h) from SIDRA Intersection analysis

Time	Sun	Mon	Tue	Wed	Thu	Fri	Sat
7:00-8:00	16.91	37.37	38.53	39.39	38.06	43.23	33.15
7:15-8:15	19.71	38.40	39.73	37.44	39.84	43.87	35.59
7:30-8:30	21.41	38.89	40.55	37.45	39.94	51.75	40.10
7:45-8:45	22.71	38.84	39.53	37.69	40.02	45.78	40.04
8:00-9:00	24.52	35.32	38.07	35.46	38.51	43.87	42.40
16:00-17:00	36.69	43.38	56.21	36.06	38.53	43.53	46.58
16:15-17:15	36.49	41.99	61.68	40.41	49.03	47.64	48.63
16:30-17:30	44.25	45.96	65.34	43.30	46.16	52.26	48.35
16:45-17:45	44.62	52.53	72.63	46.22	51.95	58.59	52.02
17:00-18:00	51.11	57.96	79.79	49.30	59.42	59.42	55.15

Appendix 11: Recoded video sample during data sampling collection