STUDY THE EFFECT OF VEHICLE COMPOSITION ON SATURATION FLOW AT SIGNALIZED INTERSECTIONS

Pathirage Dinushka Roshani Perera

(148311F)

Degree of Master of Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

October 2018

STUDY THE EFFECT OF VEHICLE COMPOSITION ON SATURATION FLOW AT SIGNALIZED INTERSECTIONS

Pathirage Dinushka Roshani Perera

(148311F)

Dissertation submitted in partial fulfilment of the requirements for the degree of Master of Engineering in Highway and Traffic Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

October 2018

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

The above candidate has carried out research for the Master's dissertation under my supervision.

Signature of the supervisor: Date:

ABSTRACT

Study the effect of vehicle composition on saturation flow at signalized intersections

Signalized intersections are an essential component of a road network in urban areas where the traffic congestion has been a severe problem. Capacity is the most important factor which used for designing the signalized intersections and saturation flow rate plays an important role in determining the capacity. Therefore, saturation flow can be considered as an important parameter which is used for the planning, designing and controlling a signalized intersection. It is required to obtain the accurate saturation flow rate values to control and designing the signal timing efficiently and effectively. Many countries had executed researches regarding the saturation flow rates to suit their traffic conditions and identified the major factors which affects to the saturation flow which might be not suited for our local traffic conditions.

Sri Lanka is a developing country and it is experiencing a rapid urbanization in all cities. As a result, road traffic is subjected to growing rapidly and the traffic movement has become quite complex due to all type of vehicles are sharing the same carriageway. In addition to that, those mixed traffic consist of slow moving and fast moving vehicles and vary with the size and vary with static and dynamic characteristics and maneuverability as well. With this study, it can be identified that this heterogeneous traffic condition is one of the major factor which affects the variation of the saturation flow. Large number of motorcycles and three-wheelers can be seen in the traffic stream of the signalized intersections.

The objective of this study was to collect a large sample of field measurements and identify the way of pattern of varying the saturation flow with the mixed traffic condition. In that point of view, correlation was calculated with each vehicle types with the saturation flow. From the analysis, it was found that high percentage of motorcycles and three-wheelers increase the saturation flow and high percentage of heavy vehicle and cars decrease the saturation flow.

Generally passenger car units (PCU) were assigned to various type of vehicles in this heterogeneous traffic condition in order to regularize the capacity calculation in a common base. However with this study it was clear that those values cannot be used as fixed values and that values also vary with the static and dynamic characteristic of those vehicles.

By considering all those facts it is clear that PCU values and saturation flow rates which uses for the signal timing calculation should be reviewed and corrected to suit with the local traffic condition.

Key Words: Signalized intersection, Saturation flow, Capacity, Mixed traffic, Correlation

DEDICATION

To my Parents

Who Always Encouraged Me towards the Success

ACKNOWLEDGEMENT

This research was carried out as a requirement of Master of Engineering program in University of Moratuwa under supervision of Prof. J.M.S.J. Bandara. Here I would like to express my sincere gratitude to Prof. J.M.S.J. Bandara for his invaluable help, guidance and encouragement during the development of this research. Then I would like to remind sincerely and express my appreciation to all my friends in RDA for their valuable help given for this research.

I wish to thank Engineer Gayani Rajapaksha for providing me videos of traffic streams in several Intersections. Then special thanks are extended to the staff of Planning Division of RDA for providing the requested data for my research.

Finally I would like to thank my family members and close friends for giving me an endless support and encouragement throughout the period of study.

P.D.R. Perera
148311F
Transportation Engineering Division
Department of Civil Engineering
University of Moratuwa

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
HCM	Highway Capacity Manual
PCU	Passenger Car Unit
RDA	Road Development Authority

1. INTRODUCTION

1.1. Introduction to the Saturation Flow at Signalized Intersection

Sri Lanka is undergoing a rapid urbanization and modernization as a developing country and subsequently it is experiencing rapid growth of road traffic. Heterogeneous traffic stream is sharing the same carriageway and then traffic movements are getting very much complex. As the other developing countries, transportation always confront to the challenge of accommodating the increase in small sized motorized vehicles such as three-wheelers and motorcycles than the four wheel vehicles. Therefore the traffic related parameters used in traffic engineering should be continually reviewed with the prevailing local traffic conditions. This is very important to find solutions to most common traffic related problems in urban areas.

Intersection is one of the main component in a road network and needs to be control the traffic to ensure safety and smooth flow through intersection. Signalized intersection is the most common traffic control system which are using to control the traffic flow through intersections safely and efficiently. The analysis and design of a signal systems are depend on many factors and the effectiveness and entire network performance is totally depend on the accuracy of those factors.

Traffic carrying capacity of signalized intersection is very much important in modifying existing ones and as well as designing new intersections. The saturation flow is the key factor which is used to determine the capacity, evaluate the performance of the intersection and to design the traffic signal timing. The exact value of capacity of signalized intersection can be evaluated, when we calculated the saturation flow in reasonable accuracy. Thus the saturation flow is considered as one of the most significant factor which determining the level of service and the capacity of a signalized intersection.

Saturation flow is a road traffic performance measure of the maximum rate of flow. Saturation flow describes the number of vehicles in a dense flow of traffic for a particular intersection lane group. In other words, it means, the amount of vehicles passed this intersection for the period of one hour, if an intersections approach signal is indicating green for that one hour period and the traffic is expected to be dense as possible. (Bester and Meyaers, 2007)

There are several methods to determine the saturation flow and all of them have been developed in western countries, to suite with their traffic environments. Highway Capacity Manual (TRB, 2010) also emphasize that there are various influencing factors to the saturation flow rate values in intersections. Apart from that, traffic environments in developing countries are quite different to the traffic environments in western countries and those differences arises due to several factors which is given below; (Turner and Harahap, 1993):

Vehicle mix	- Different types of vehicles with varying size, different maneuverability and operating performances.
Driver behavior	- Violation of traffic rules and not followed the particular lane
Public transport	- Different types of buses, driving styles and stopping places.
Roadside activity	- Generating parking due to roadside land use

In this study, saturation flow rate was calculated by measuring the actual classified traffic flow during the saturated green intervals of the green phases at different approaches of four intersections in the field. Then calculated the correlations between each vehicle types with the saturation flow.

1.2. Problem statement

It would be much easier to analyze the traffic operation at signalized intersections, if all vehicles were identical in the traffic stream. However saturation flow is depend on the type and the proportion of various vehicles in that traffic flow. Sri Lankan urban traffic flow is heterogeneous and traffic stream in most of the places consist of a variety of vehicles which are differentiated based on their static and dynamic characteristics. The fundamental relationships for estimating saturation flow rates, PCU factors are not appropriate for developing country like Sri Lanka due to these fundamental difference. All the parameters should be estimated to corresponding to the prevailing local traffic condition for the accuracy of signal design. Hence it is required a different approach to analyze this situation. The existing models of saturation flow developed for homogeneous traffic and not for the heterogeneous traffic condition.

When designing the traffic signal systems, the current practice is to assume an ideal value for the saturation flow rate and adjusted it for the prevailing condition using adjustment factors developed in developed countries. This cannot be considered as acceptable and it may lead to increase in congestion at the intersection. The accurate saturation flow is an input for the optimal signal timing and small variation in saturation flow could affect the cycle length and it will directly affect to the efficiency and operation of the urban intersections.

Therefore the saturation flow needed to be derived and adjusted to suite the local traffic condition. The factors which are affecting to the accurate estimation of saturation flow should be identified and then those factors should be calibrated accordingly. Hence the objective of this study is to identify the saturation flow rate with respect to the Sri Lankan heterogeneous traffic condition

1.3. Objectives

1. Identify the factors affecting to the rate of saturation flow rate at signalized intersection in Sri Lankan traffic condition

2. Find out the effect on traffic composition (two wheelers, three-wheelers, cars and heavy vehicles) to the variation of the saturation flow rate of a signalized intersection.

3. Evaluate the accuracy of the PCU factors using for the capacity calculations (Saturation flow) in Sri Lanka

2. LITERATURE REVIEW

2.1 Calculation of Capacity and Saturation flow at Signalized Intersection

Traffic signals considered as one of the traffic control technique which used to control the traffic through intersections in safely and efficiently. Accurate estimation is required by traffic engineers to estimate the capacity of the signal. Then it can be designed the timing plans for signal light and evaluated the level of service (operational analysis) of existing ones as well.

Highway Capacity Manual, 2010 indicates that the saturation flow is a macro performance measure of junction operation. It is an indication of the potential capacity of a junction when operating under ideal conditions. Capacity (c) is expressed as the maximum number of vehicles that can be expected to pass through the intersection under prevailing traffic and signalization conditions during fifteen minute period.

$$c = s.\frac{g}{C}$$

Where:

c = Capacity (veh/hr)

s = Saturation flow rate (veh/hr)

g = Green time (sec)

C = Cycle length (sec)

Accordingly, the saturation flow rate (s) is the main parameter which used to derive the capacity of interstation.

The Highway Capacity Manual (TRB, 2010) described an ideal saturation flow rate as one thousand nine hundred passenger car per hour per lane (1900 pc/hr/ln). However it indicates that, this default value may not be essentially applicable to all traffic conditions around the world due to driver behavior, different road characteristics in those locations and different operational traffic conditions. The HCM 2010 clearly emphasized the need of adopting locally measured values for other traffic environments outside the North America.

Ideal condition indicates in TRB-2010, assumed the following:

- 3.6m lane width
- Flat Gradient
- No Heavy vehicles
- Uniform movement type as only through movement or turning movement
- No bus stops or parking near the intersection
- No cyclists or pedestrians

The rectangular model of saturation flow at a signalized intersection (an ideal view) is demonstrated in *Figure 2-*. (Turner and Harahap, 1993):

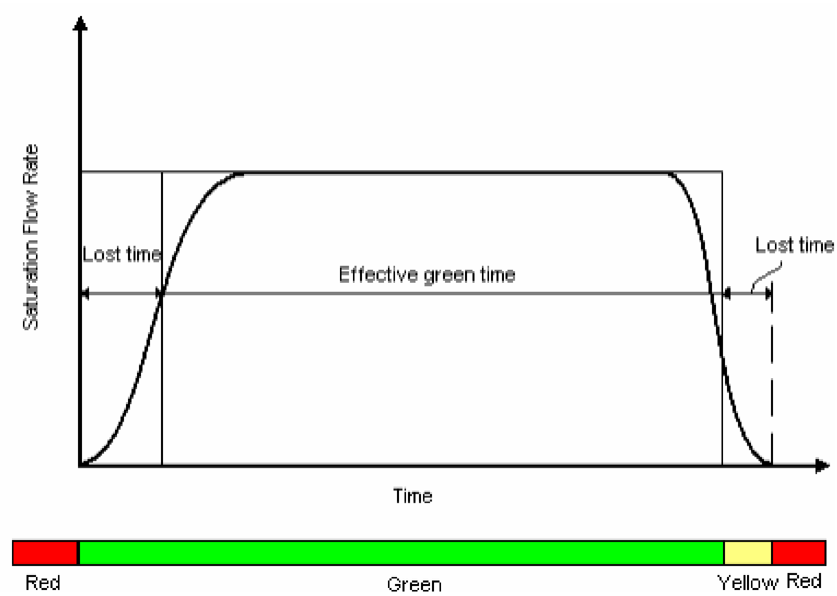


Figure 2-1: Idealized view of saturation flow

When the traffic signal light indicates green, there is a small gap between first few vehicles due to the reaction time of the first driver. Then the rate of vehicle crossing the stop line get increased and it is determined by the cars they are following.

Afterwards, the headway between the vehicles get constant and plateau of this profile is represented this constant rate.

Generally, the queue formed when the signal lights were in red will be much longer to clear during the green phase in saturated intersections. During this green time, cars will be following each other with constant gap. When the signal light shows the amber, the flow rate will be dropped and this decreasing rate will be the same as the increasing rate at the start and finally will be stopped when the signal light shows red.

The saturation flow is calculated by converting the curved profile in to rectangular profile. Then the dimensions will be measured by with the idea of effective green time and lost time. The lost time is taken as the time from start point to the point where the vehicles are following half the maximum flow rate and time from where vehicles are following at half the maximum flow rate at the latter part of the saturation to the beginning of the red phase. **(**Md Hadiuzzaman, et al, 2008)

However, following equation is used to determine the saturation flow rate in the field.

$$s = \frac{3600}{h_s}$$

where:

s = Saturation flow rate

3600 = number of seconds per hour

h_s = Saturation headway (s)

Generally saturation flow rate is expressed in veh/hr in developed countries where the traffic conditions are almost homogeneous. However in developing countries it is experiencing a heterogeneous traffic conditions and required to regularize the saturation flow in a common base as passenger car units per hour (pcu/hr). From that, different sites with different vehicle composition can be compared easily. Passenger car units are indicates the space occupy by different type vehicles relatively passenger car. The term “passenger car equivalent” was introduced in the 1965 U.S., Highway

Capacity Manual (HCM) and defined as "the number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions".

The passenger car unit values are not fixed but vary with the geometry of the intersection, static and dynamic characteristics of vehicles, and traffic composition as well.

2.2 Start-Up Lost Time and Saturation Headway

Start-up lost time needed to be understood to determine the accurate saturation flow. The principle for this start-up lost time can be described as follows (Bester and Varndell, 2002):

The vehicles in the queue will start to cross the intersection when the signal phase changes to green. Generally the vehicle headway is described as time gap between two vehicles which are crossing the stop line. Time taken to pass the rear wheel of first vehicle will be the first headway and the second headway will be the time gap between the first and second vehicle's rear wheels cross the stop line.

In this process, the first driver observes the start of the green time and then react to the signal change accordingly. Then the driver accelerates through the intersection and getting a quite long headway. Afterwards, the second driver entered to this process with exception of this reaction time and accelerating time. It's mainly due to this driver can react and start accelerating during the first vehicle moving time. This resulted a quite shorter headway than the first headway due to having an extra vehicle length in which to accelerate. This process will continue until a certain number of vehicles cross the intersection and start-up reaction and acceleration has no longer effect on the headway of the vehicle. Headways will be remain constant from this point onwards until the green time has ended or all vehicles cleared. This constant headway is recognized as the saturation headway and can be start to occur between the third and sixth vehicle in the queue. Figure 2-2 illustrates the situation described above.

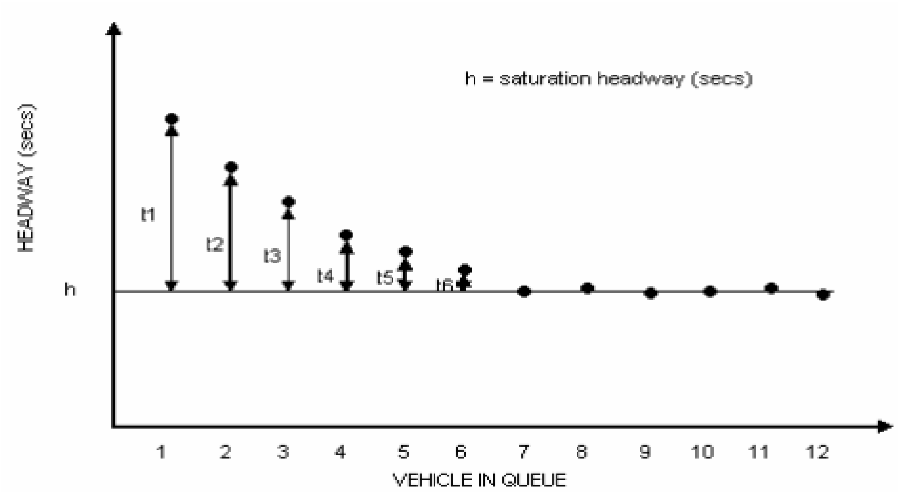


Figure 2-2: Headways at a traffic interruption (Bester and Varndell, 2002)

The following equation will be used to calculate the above mentioned saturation headway for the example in figure 2-2.

$$h_s = \frac{\sum_{j-n}^{i} h_j}{(l+1-n)} = \frac{(h_7 + h_8 + h_9 + h_{10} + h_{11} + h_{12})}{(12+1-7)}$$

Where;

h_s = saturation headway

l = last queued vehicle position

h_j = headway of j^{th} queued vehicle

n = position of queued vehicle form where saturation flow region started

As in the HCM, saturation flow is calculated by averaging the discharging headway from the fifth vehicle onwards in the queue up to last vehicle and it is as follows;

$$H_s = \frac{\sum_{i=1}^{m} \sum_{j5}^{ni} Hij}{\sum_{i=1}^{m} (ni-4)}$$

Where,

H_s = saturation headway (sec)

H_{ij} = discharge headway of jth queued vehicle in cycle i (sec)

n_i= number of vehicles in queue of cycle i, ni>4; and

m = total number of cycles during an observation period

2.3 Measurement Methods of Saturation flow rate

There are three methods available for the measurement of the saturation flow. They are described as follows;

1. The Road Note 34 Method (1963)

The procedure of this method is to obtain classified counts of vehicles which cross the stop line within the approach width in three saturated green intervals. Then the saturated flow is calculated as the number of vehicles in the middle interval divided by the length of that middle interval.

2. The Average Headway Method (Green shields et al. 1947; TRB 1997)

This is the most commonly used method which estimates the average time headway between the vehicles discharging from queue as they pass the stop-line. Time headway is measured as the time taken to preceding vehicles rear bumper crosses the stop line to the own vehicles rear bumper crosses the stop line. The first four vehicles are skipped from the calculation to avoid the effect of accelerating time and reaction time of those vehicles. The saturation flow rate is calculated as reciprocal of the mean headway.

3. Multiple Liner Regression Methods (Branston et al., 1978,1981)

Recently it was found this method as an easiest method of measure the saturation flow. It is developed an equation involving saturated green time, number of vehicles in various categories, and lost time in this method. Then a regression analysis is performed to yield the saturation flow, the lost time and the passenger car equivalents for vehicles other than passenger cars

2.4 Method of Measurement

From a previous study of Hounsell, 1989 & Leong, 2004, it was found that the average headway method is the best method to estimate not only saturation flows but, PCU factors and lost time as well. The Road Note 34 also provides good prediction of saturation flows and lost times, even though it sometimes underestimates the lost times. Multiple regression method is also recorded as a good method of measurement of deriving PCU factors and saturation flow rates, especially for non-lane based traffic. Usually it's very difficult to collect headway measurements in those non lane based traffic conditions.

After considering all of above facts, it was planned to measure the individual headways of each vehicles in particular lane and then averaged them to obtain the appropriate saturation flow rates. Consequently, it was recorded as the best way to obtain the accurate values.

2.5 Influencing Factors for the Saturation flow

The Highway Capacity Manual (TRB, 2010) and many researchers have found many influencing factors to the variation of saturation flow rate and summarized as below;

Saturation flow rates are affected mainly by three type of factors

1. Difference in geometric condition
   This includes lane width, number of lanes, horizontal curvature (right turn and left turn vehicles), speed limit and gradient

2. Traffic composition and operating characteristics of vehicles
   This includes mixed traffic condition, proportion of turning vehicles and number of heavy vehicles

3. Human behavior

   This is the most complicated factor which can't be simulated easily. This affects the space between moving vehicles and their reactions to the particular situations.

Highway Capacity manual 2010 defines many adjustment factors to the base saturation flow to suit for the each situation and it is given below;

$$S = So*N*fw*fHV*fg*fp*fbb*fa*fRT*fLT$$

Where,

So = Ideal saturation flow rate per lane (1800 pcphgpl)

N = number of lanes in the lane group,

Fw = adjustment factor for lane width (12' lane is standard)

fH = adjustment factor for heavy vehicles in the traffic stream

fg = adjustment factor for approach grade

fp = adjustment factor for the existing parking activity in that lane

fbb = adjustment factor for the blocking effect of local buses stopping

fa = adjustment factor for area type

fRT & fLT = adjustment factor for right and left turns

As per the latest edition of HCM 2016, TRB new adjustment factor for work zone and combined the two adjustment factors of heavy vehicle and gradient factors.

Even though these factors were defined in HCM 2010 and HCM 2016, those derivation suit for the urban traffic conditions in industrialist countries and not for the developing countries. The vehicles like motorcycles and three-wheelers has not considered as they are in less numbers on those countries, however developing countries are experiencing quite considerable sharing of those vehicle types with cars. Therefore many researchers have investigated errors in those derivations and found their own derivations which suit for their local traffic conditions.

2.6 Previous Researches

Several researches have been conducted in various parts of the world regarding the saturation flow rates under normal circumstances. Table 2-1 shows the summery of some earlier researches where conducted and mean saturation flow obtained in each study.

Table 2-1: Mean Saturation Flow Rates in Earlier Studies in Different Countries

Researcher	**City, Country**	**year**	**Mean Saturation flow rate (pc/hr/ln)**
Mukwaya and Mwesige	Ughanda	2012	1,579, 1,774, and 1,470
Jobair bin Alam et al.	Makah, Saudi Arabia	2011	2,500
Shao et al	China	2011	1,800
Bester and Meyers	Stellenbosch, South Africa	2007	2,076
Rahman et al	Dhaka, Bangladesh	2005	2,048
Rahman et al	Yokohama, Japan and	2005	1,900
Dunlap	Pennsylvania	2005	1,800
Khaled Hamad and Hassan Abuhamda	Doha, Qatar	2015	2,323

When examine the all above results obtained from various countries, it is clear that the base saturation flow is deviate with the local traffic condition and local driver behaviors. Bester and Meyers (2007) concluded their research that the aggressiveness of the local divers could be an indication of the higher saturation flow in South Africa. It tends to decrease the average headway values compared to HCM 2010.

3. METHODOLOGY

This chapter mainly describes the summary of the methodology adopted for this study.

3.1 Data Collection

Data Collection played the main role and it was done in two stages. Collection of preliminary data and field data are those stages and described below;

3.1.1 Collection of Preliminary Data

Suitable signalized intersection locations were selected for the study based on following criteria. The main objective for this criteria was to avoid the other variation factors which contributed for the saturation flow other than the mixed traffic condition.

- Lane width varying from of 3.1m to 3.7
- No parking adjacent to a travel lane with in 50m of the stop line
- No disturbance form right turning vehicles on the other approaching lane
- No disturbance form left turning vehicles on the other approaching lane
- No disturbance from pedestrians
- The approach's grade is level

Accordingly to the above criteria, four main intersection was selected for the study. They are shown in Figure 3-1, Figure 3-2, Figure 3-3 and Figure 3-4.

Figure 3-1: Dematagoda Signalized intersection which intercept the Kolonnawa Road and Baseline Road

Figure 3-2: Cotta Road Leg of Borella Signalized Intersection

Figure 3-3: Senanayake Signalized Intersection

Figure 3-4: Palanthuna Signalized Intersection

The surface condition of the intersection has an effect on the traffic movement speed and therefore surface condition of all four intersections are assumed as in same condition based on visual inspection. The location map of these intersections are given in Figure 3-5.

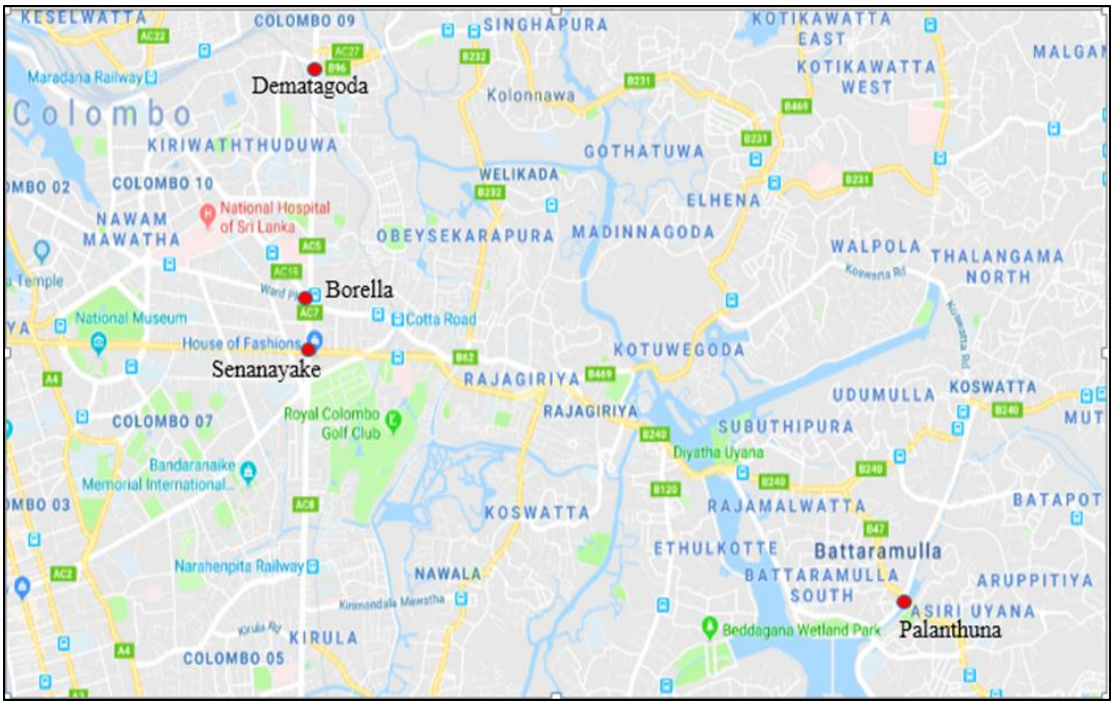


Figure 3-5: Location Map of Intersections

3.1.2 Collection of Field Data

Each legs of traffic movements in peak times were videotaped in Dematagoda and Palanthuna Intersections and data of signal timing such as cycle length and green times were recorded. Videotapes of traffic movements in Borella and Senanayake intersections which used for this study were obtained from the Department of Civil Engineering, University of Moratuwa.

Data extraction from the videotapes was the main part of the data collection. Headway measurement of each vehicle during the saturated time period (Refer to Section 4.2) in green interval were obtained using stop watch and leading vehicle, lagging vehicles were recorded as well. Separate right turn lanes and left turn lanes were omitted when extracting data.

4. DATA ANALYSIS AND RESULTS

4.1 Calculation of Saturation flow

Calculated the average headway and saturation flow rate for each cycle and obtained the mean saturation flow rate. First four vehicles were skipped when calculating the headway due to initial lost time of those vehicles. The results are given in Table 4-1.

Table 4-1: Results of Average Headway and Saturation Flow Rate

Intersection	**Headway**		**Saturation flow**	
	Average headway (s)	**Std. Deviation**	**Average Saturation Flow (veh/hr/lane)**	**Std. Deviation**
Borella	1.46	0.18	2,496	289
Dematagoda	1.32	0.20	2,785	396
Senanayake	1.35	0.16	2,705	297
Palan thuna	1.38	0.10	2,626	157

4.2 Vehicle Compositions of Intersections

It was necessary to identify the different vehicle compositions when analyzing the saturation flow rate in these different intersections. According to HCM 2016, headway measurement has to be taken after 5^{th} vehicle onwards to avoid the initial lost time. Therefore the first four vehicles were skipped for this calculation. Apart from that motorcycles which were gathered in front of the queues and vehicle which does not follow the lane were skipped when calculating the saturation flow as those vehicles couldn’t take for the headway measurement practically. Therefore, vehicle composition were mainly calculate by avoiding these front gathered motorcycles as well as motorcycles which does not follow the lane and first four vehicles in the queue for the analysis purpose and it is given in Figure No. 4-1, 4-2, 4-3, 4-4. In addition to that, actual vehicle composition and the vehicle composition which used for the analysis were summarized in Table 4-2.

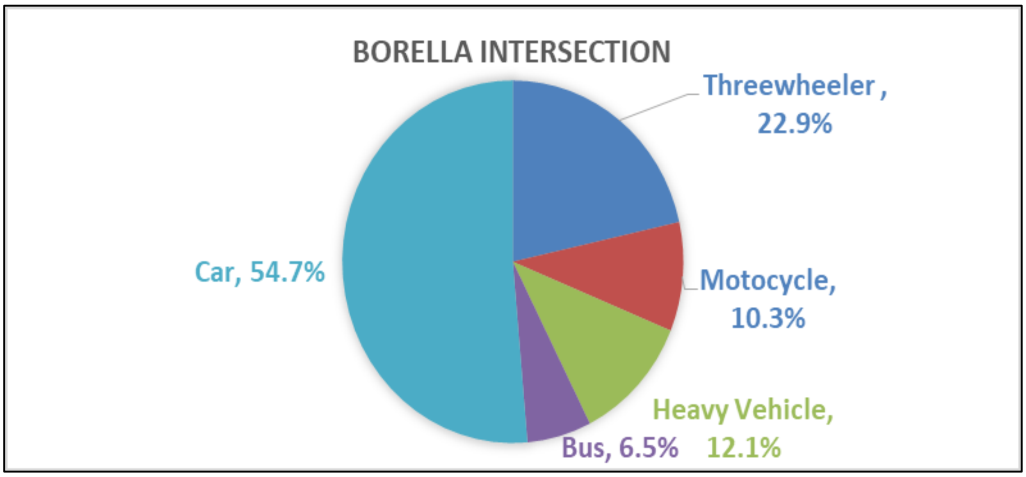


Figure 4-1: Vehicle Composition in Borella Intersection

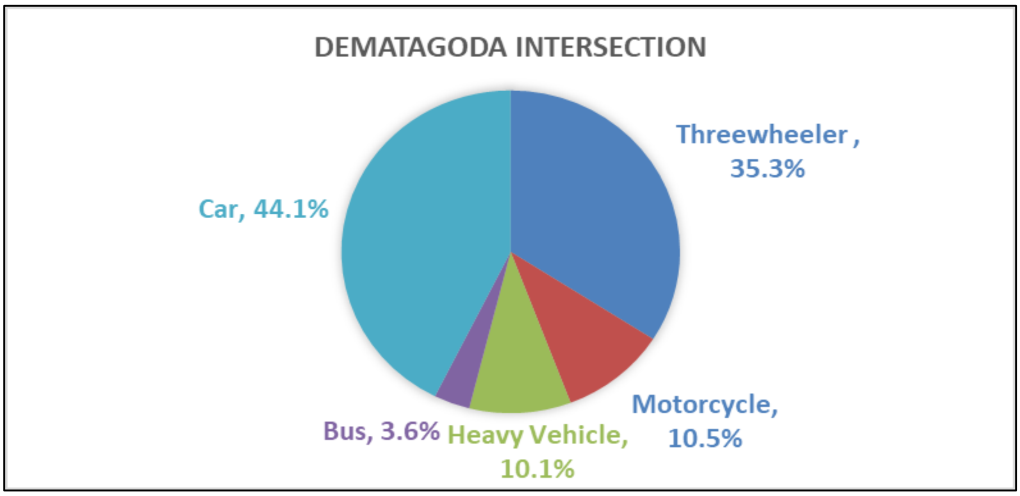


Figure 4-2: Vehicle Composition in Dematagoda Intersection

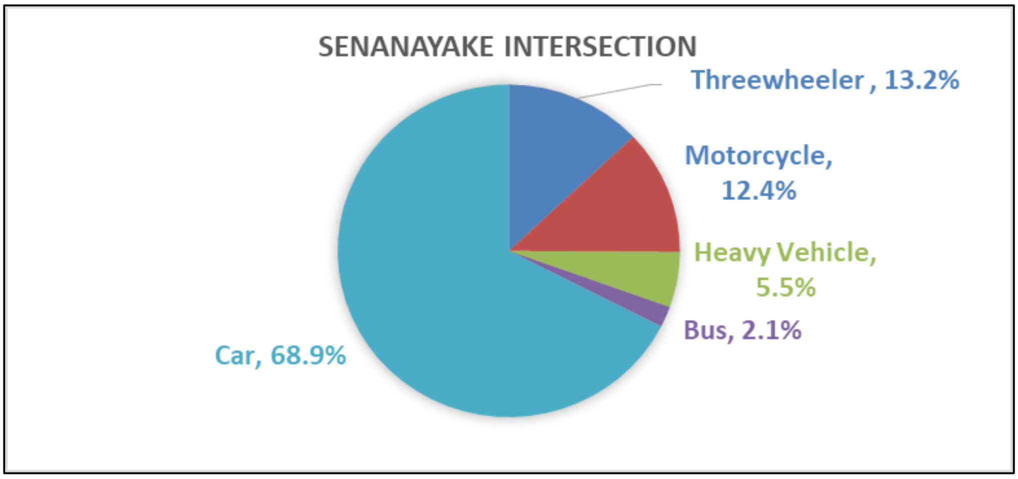


Figure 4-3: Vehicle Composition in Senanayake Intersection

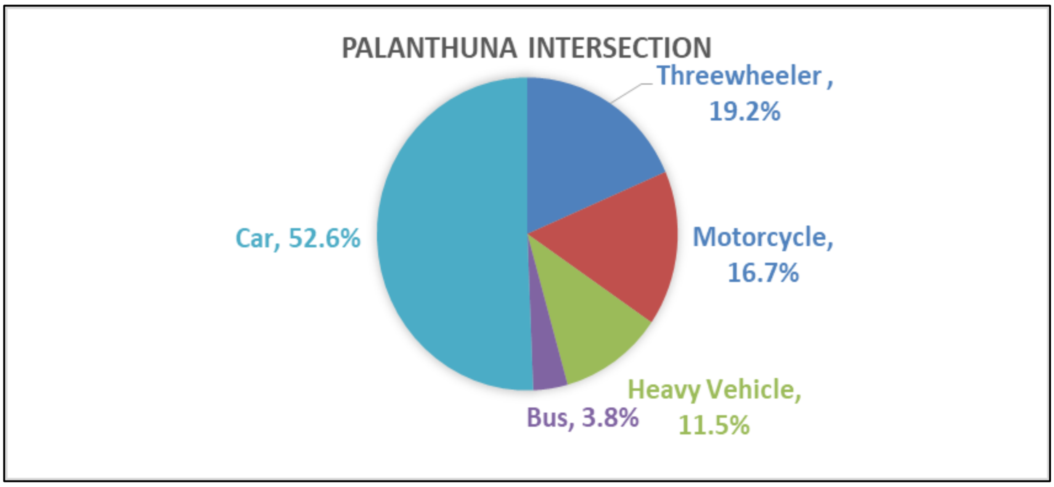


Figure 4-4: Vehicle Composition in Palanthuna Intersection

The summery of the vehicle composition of all intersections are given in Table No 4-2.

Table 4-2: Summery of Vehicle Compositions in Each Intersection – Part 01

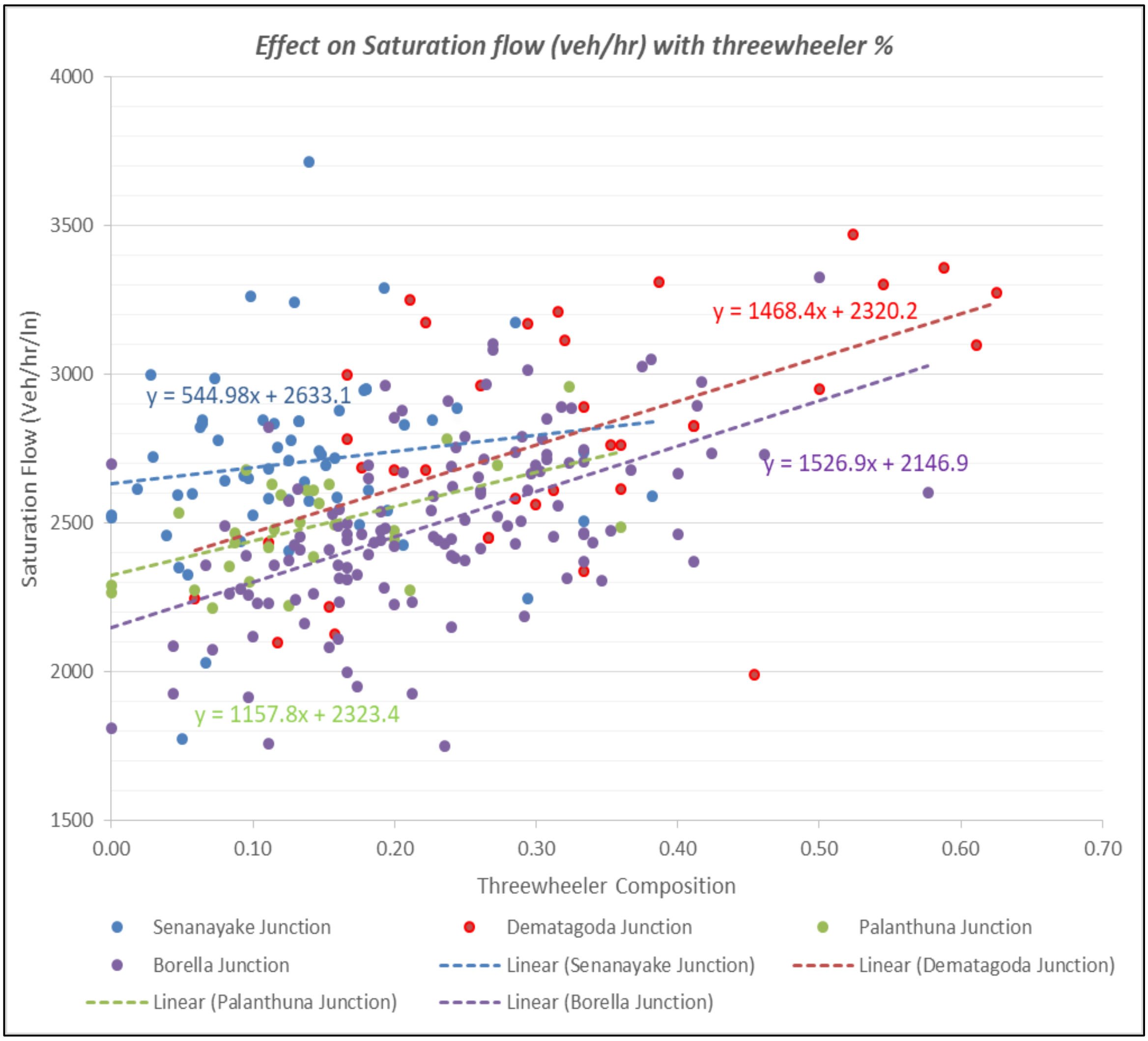
Intersection	Three-wheeler %		Motorcycle %		Heavy Vehicle %	
	Used for Calculation	Total Count	Used for Calculation	Total Count	Used for Calculation	Total Count
Borella	22.9%	18.3%	10.3%	21.8%	12.1%	8.7%
Dematagoda	35.3%	27.8%	10.5%	24.2%	10.1%	6.3%
Senanayake	13.2%	11.8%	12.4%	18.7%	5.5%	4.5%
Palan thuna	19.2%	17.7%	16.7%	21.9%	11.5%	9.4%

Table 4-3: Summery of Vehicle Compositions in Each Intersection – Part 02

Intersection	Bus %		Car %	
	Used for Calculation	Total Count	Used for Calculation	Total Count
Borella	6.5%	4.7%	54.7%	51.1%
Dematagoda	3.6%	2.2%	44.1%	41.6%
Senanayake	2.1%	1.6%	68.9%	65.0%
Palan thuna	3.8%	3.1%	52.6%	51.0%

4.3 Calculation of Pearson Correlation between Saturation Flow and Each Vehicle Type

It was calculated the Pearson Correlation between each vehicle type with the saturation flow rate. The results are given below;



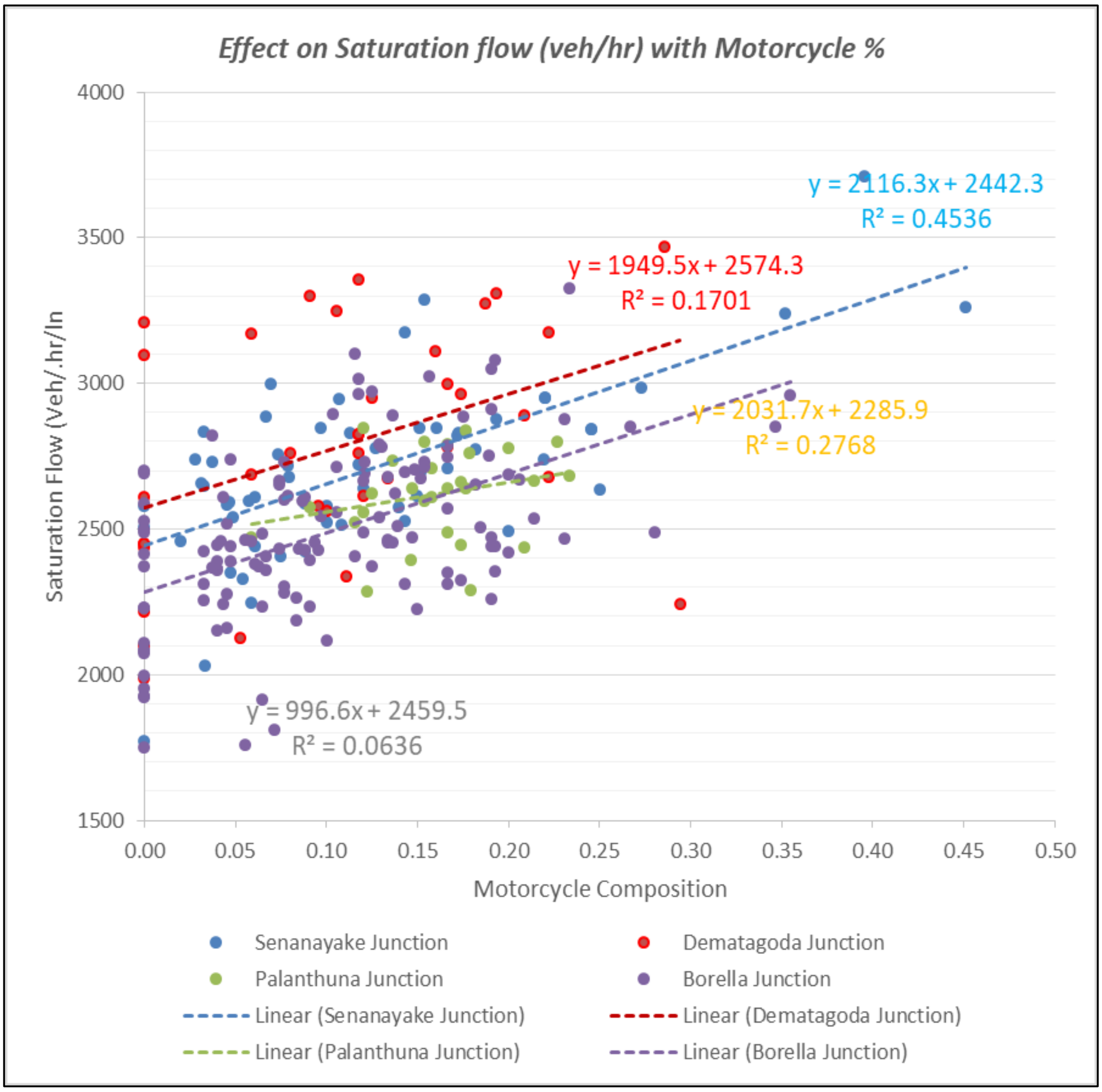
	Borella Intersection	Senanayake Intersection	Dematagoda Intersection	Palanthuna Intersection
Pearson Correlation	0.545**	0.148	0.545**	0.242
Sig. (2-tailed)	0.000	0.258	0.001	0.198

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Figure 4-5: The Effect on Three-wheeler Composition with Saturation flow

As per the results obtained above, there is positive correlation between the saturation flow and three wheeler composition. Gradients are getting lowered when the three-wheeler composition is reduced. However it is observed that the rate of increasing the saturation flow is quite lower with the increasing of the three-wheeler percentages.

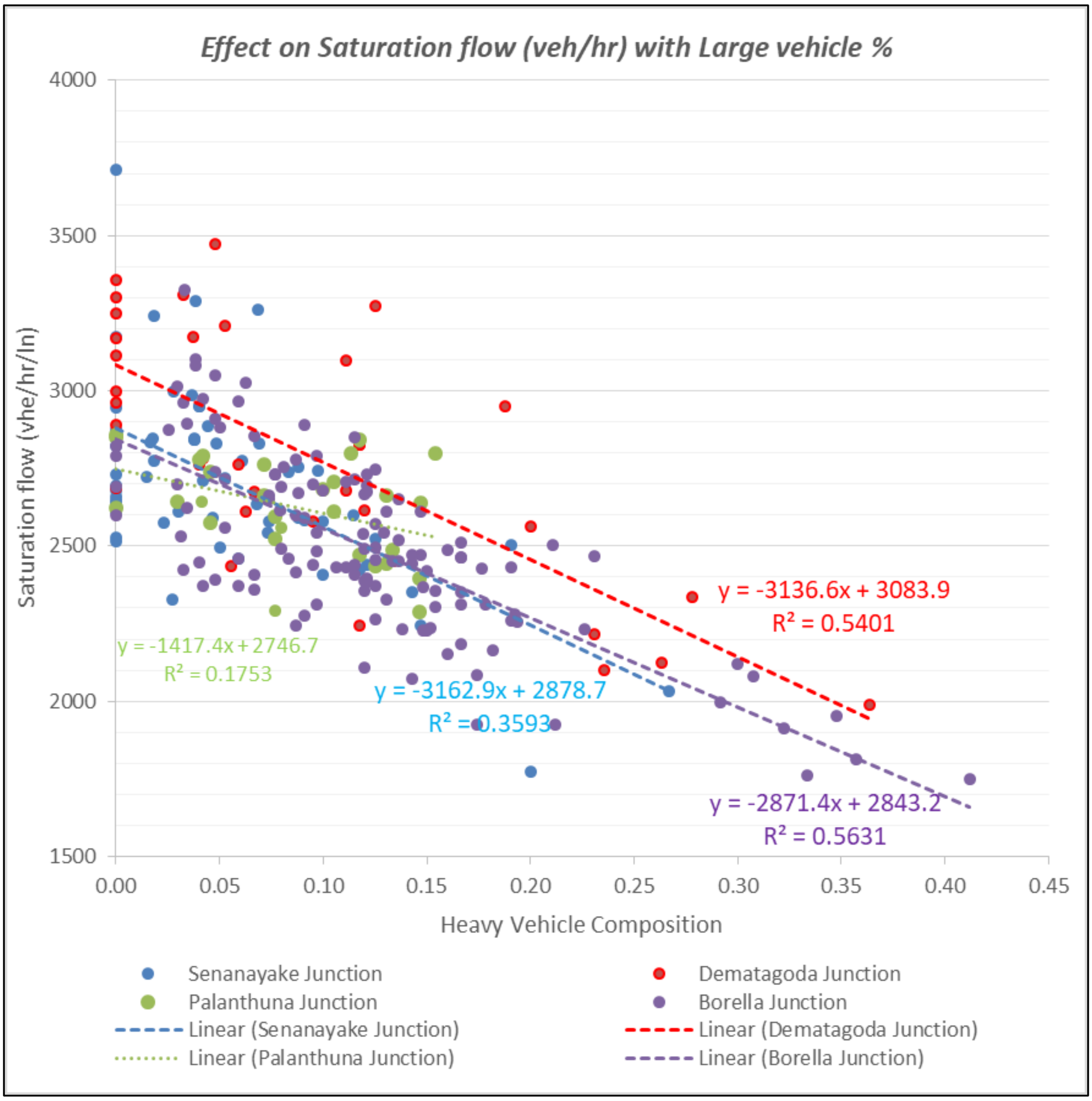


	Borella Intersection	Senanayake Intersection	Dematagoda Intersection	Palanthuna Intersection
Pearson Correlation	0.530**	0.673**	0.421*	0.252
Sig. (2-tailed)	0.000	0.000	0.010	0.180

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

Figure 4-6: The Effect on Motorcycle Composition with Saturation flow

It is observing positive correlation between the saturation flow and the motorcycle composition and the rate of increasing the saturation flow is quite lower with increasing of the motorcycles.



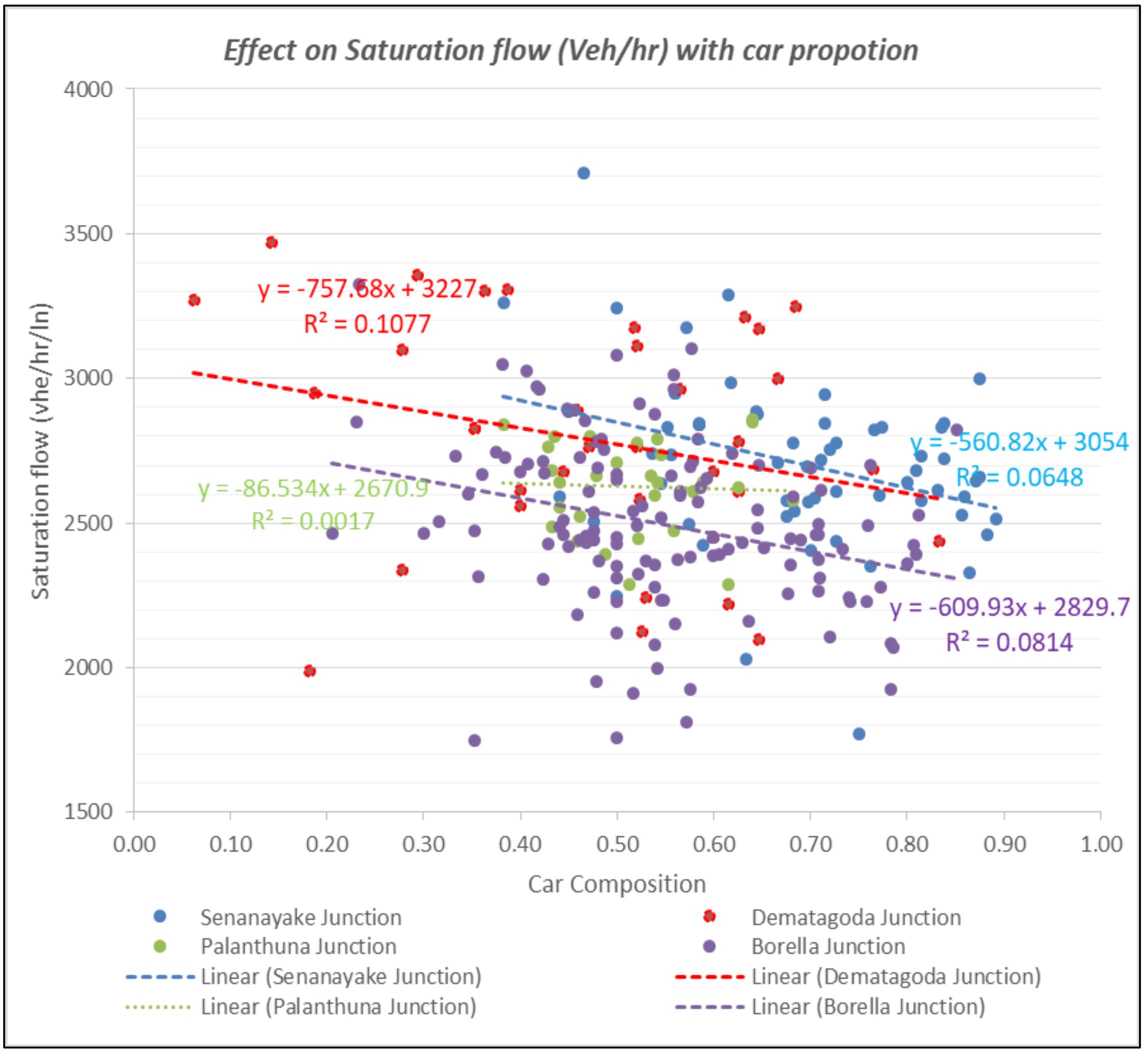
	Borella Intersection	Senanayake Intersection	Dematagoda Intersection	Palanthuna Intersection
Pearson Correlation	-0.743**	-0.352**	-0.684**	-0.439*
Sig. (2-tailed)	0.000	0.006	0.000	0.015

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 4-7: The Effect on Heavy Vehicle Composition with Saturation flow

As per the results obtained above, there is negative correlation between the saturation flow and the heavy vehicle composition, which means saturation flow rate is getting lowered when increasing the heavy vehicles in that traffic flow. However the rate of decreasing the saturation flow is quite lower at the high composition of the heavy vehicles.



	Borella Intersection	Senanayake Intersection	Dematagoda Intersection	Palanthuna Intersection
Pearson Correlation	-0.286**	-0.326*	-0.258	-0.040
Sig. (2-tailed)	0.001	0.011	0.129	0.834

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Figure 4-8: The Effect on Car Composition with Saturation flow

It is observing negative correlation between saturation flow with the car composition in every intersection. It is clear that the saturation flow is dropping when increasing the cars compared to other vehicles.

4.4 Calculation of Saturation flow using available PCU Values

Generally saturation flow is derived using the passenger car unit as the common platform. Currently there is no proper derivation of Passenger Car Units for intersection in Sri Lanka. Therefore it is converted all the vehicles to passenger car units using factors currently using in RDA for intersections (Geometric Design Standards of Roads, 1998). Those factors are given in Table No 4-4.

Table 4-4: PCU factor values used in RDA

Vehicle Type	PCU factor
Motorcycle	0.4
Three-wheeler	0.6
Car	1.0
Bus	2.4
Heavy Vehicles	2.0

(Source: Geometric Design Standards of Roads. Road Development Authority, 1998)

The results obtained for the saturation flow rate using PCU factors are given in Table No. 4-5.

Table 4-5: Saturation flow rate in Veh/hr and PCU/hr

Intersection	Saturation flow Veh/hr/ln	Saturation flow PCU/hr/ln
Borella	2496	2553
Dematagoda	2785	2716
Senanayake	2705	2562
Palan thuna	2626	2493

4.5 Calculation of Pearson Correlation between Saturation Flow Rate with PCU Values and Each Vehicle Composition

Then correlation was calculated between saturation flow calculated by PCU factors with each vehicle composition. The results are given below;

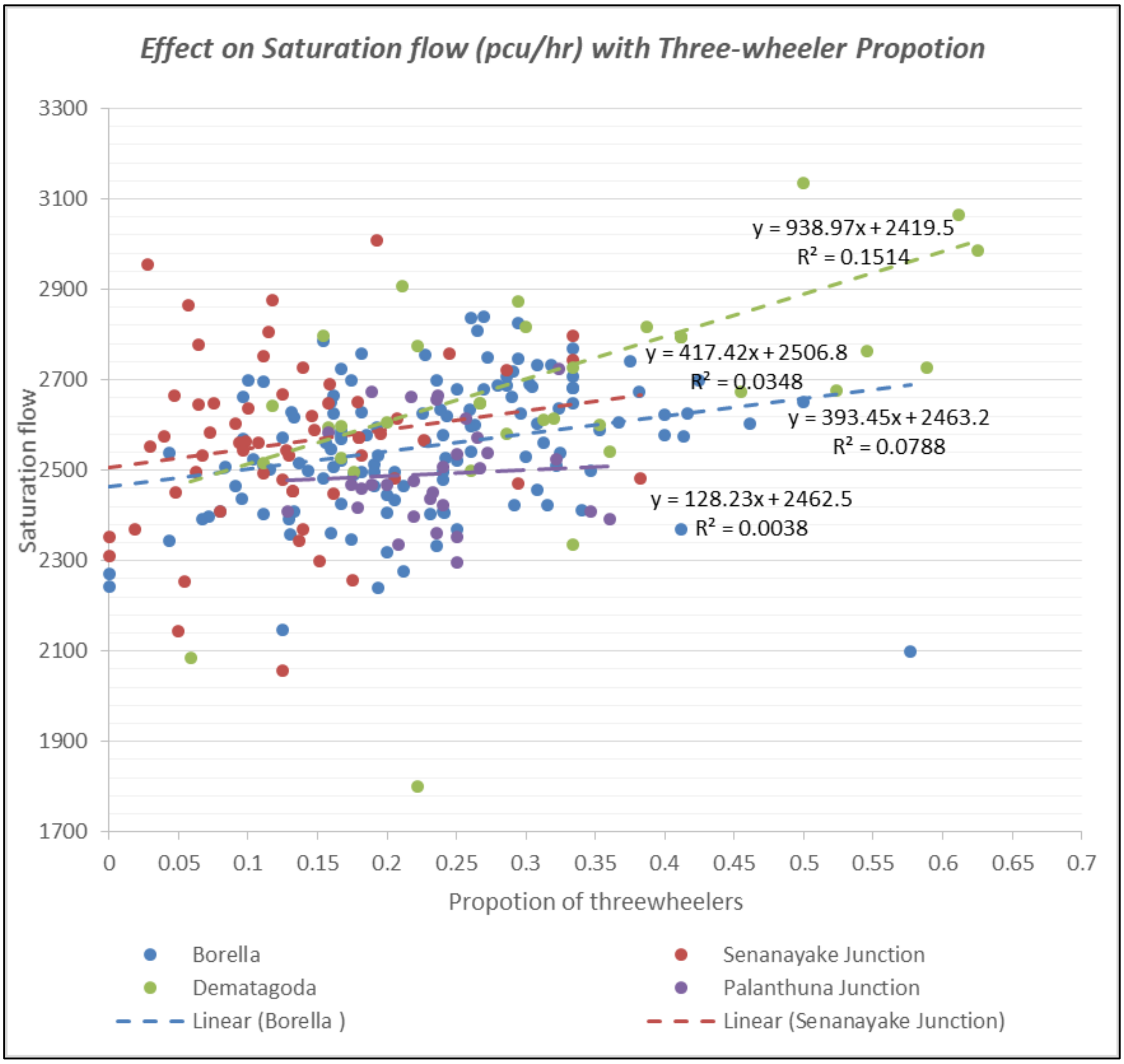


Figure 4-9: The effect on Saturation flow (pcu/hr) with Three-wheeler composition

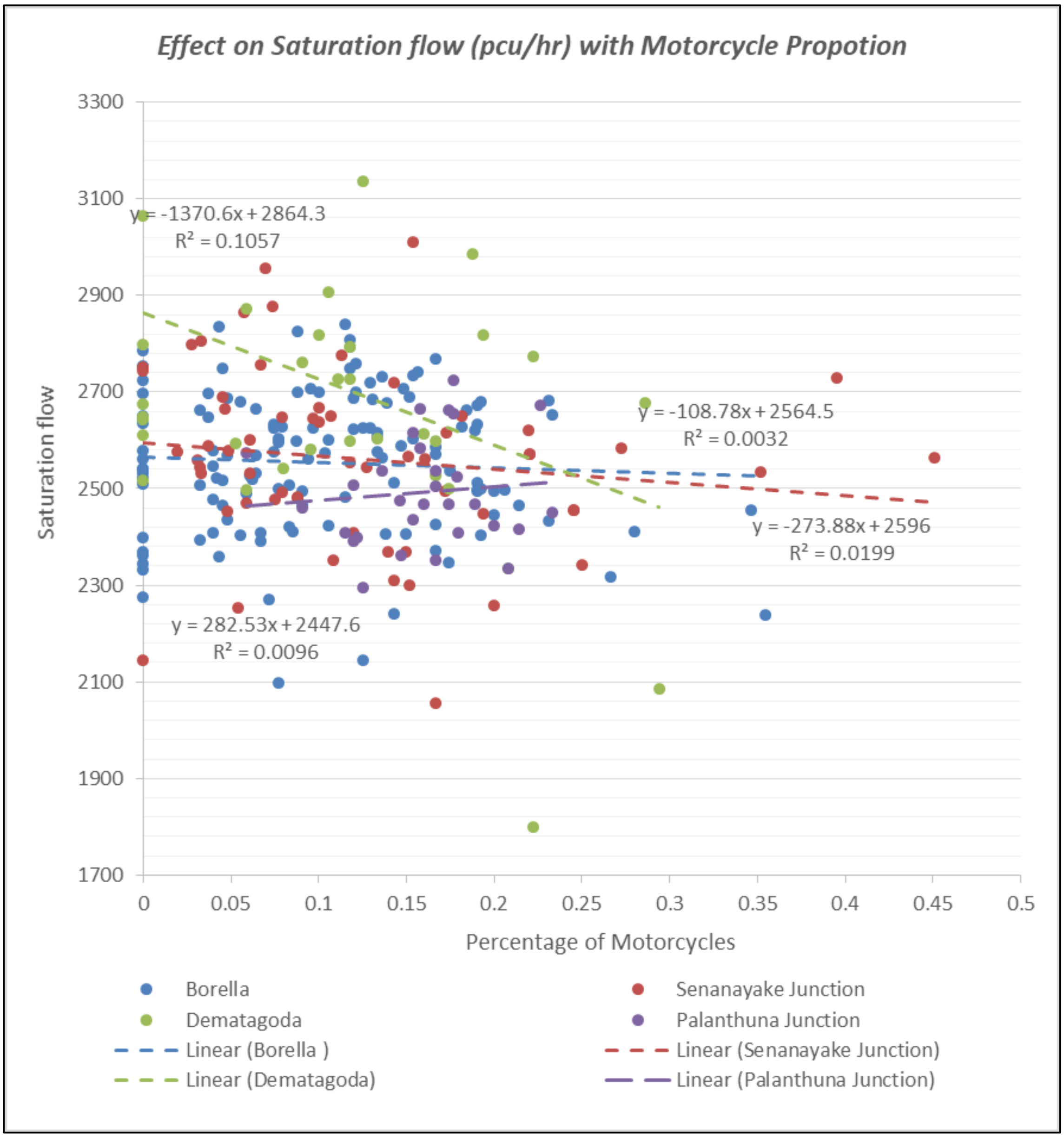


Figure 4-10: The Effect on Saturation Flow (pcu/hr) with Motorcycle Composition

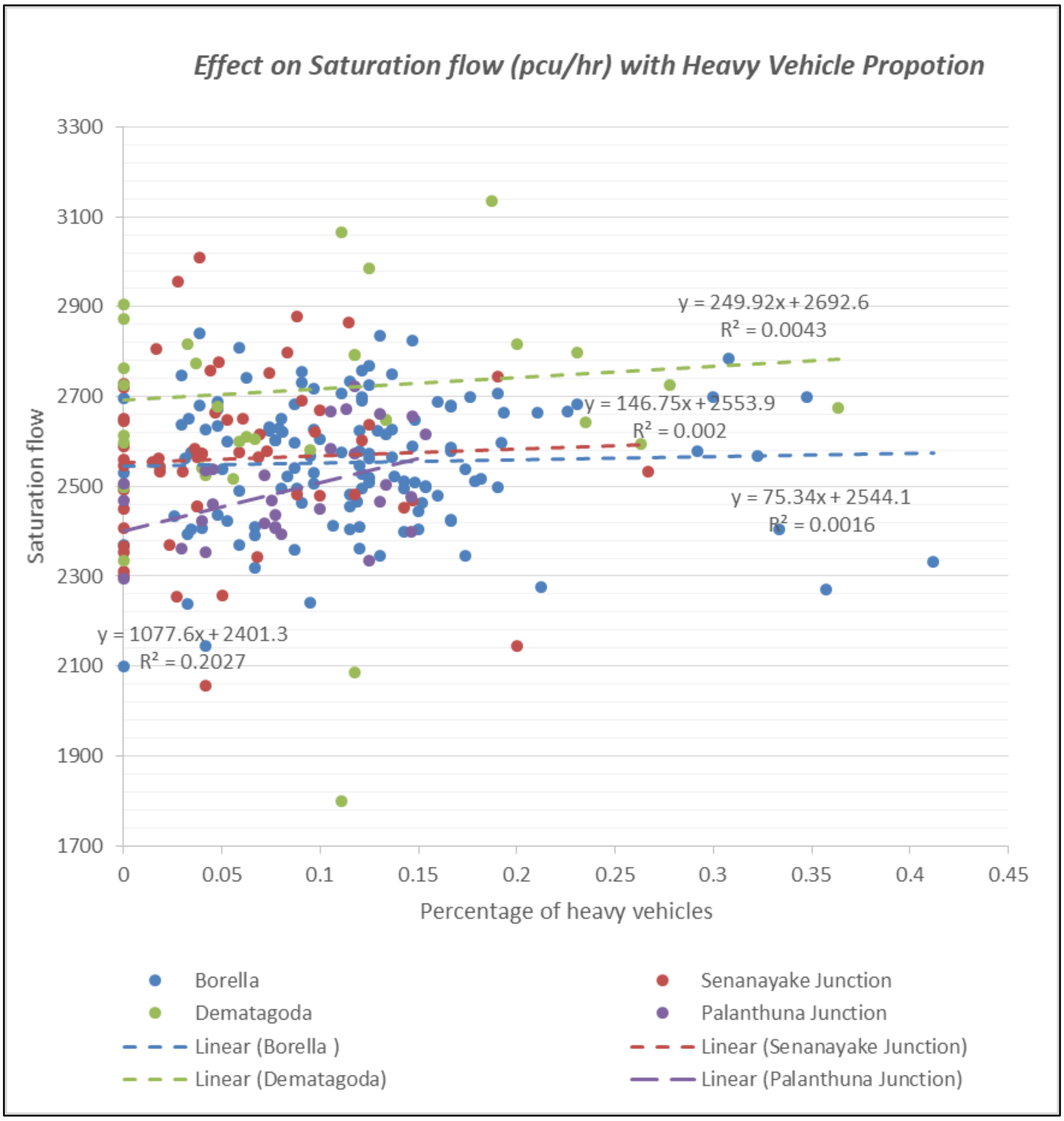


Figure 4-11: The Effect on Saturation Flow (pcu/hr) with Heavy Vehicle Composition

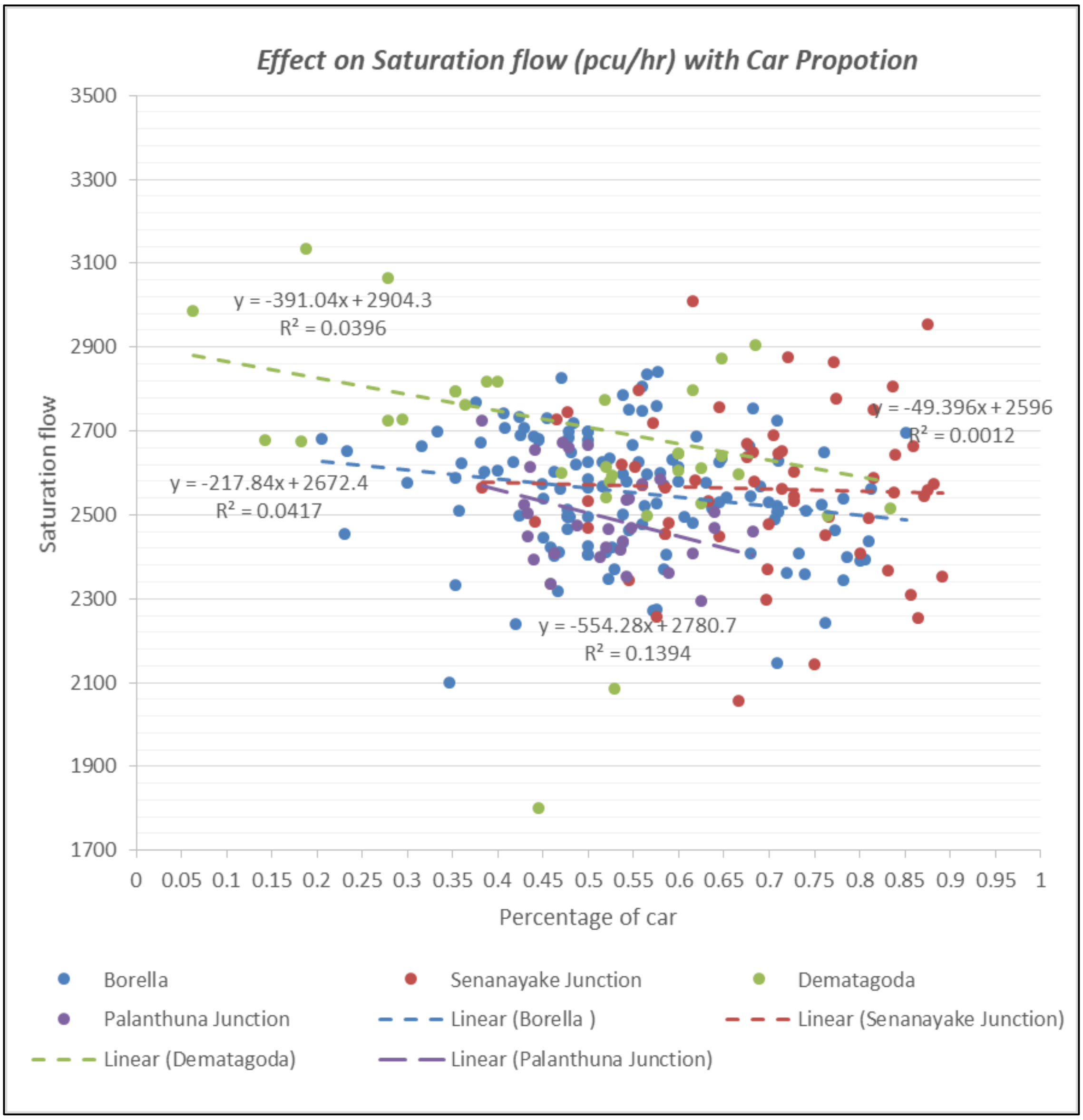


Figure 4-12: The Effect on Saturation Flow (pcu/hr) with Car Composition

It was expected constant value (flat gradient) of saturation flow (PCU/hr/ln) for the variation of each vehicle categories. However it is observed that the saturation flow is varying positively and negatively with the variation of the each vehicle composition.

Therefore it is clear that used PCU factors are not harmonized with the actual condition. Therefore calculation of PCU factors which to obtain the actual condition was done and the procedure is given below;

4.6 Calculation of PCU Factors

Synchronous regression method was used to obtain the PCU values in this study. Classified vehicle counts were taken after 3 sec of start-up lost time, following this method. Regression analysis was carried out between the saturation green time and number of each category of vehicles crossing the stop line during the saturated green time. Linear relationship is assumed between the variables. All the vehicles were grouped into five categories as large bus, large vehicles, car, three-wheelers and motorcycles.

The regression equation as follows;

$$T = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5$$

Where ; T = saturated green time (sec),

a_0 = y-intercept,

a_1 = coefficient of car,

$a_{2,}$ $a_{3,}$ $a_{4,}$ a_5 = coefficient for other four type of vehicles: large bus, large vehicles, Three-wheelers and motor cycles respectively,

$x_{1,}$ $x_{2,}$ $x_{3,}$ $x_{4,}$ x_5 = number of vehicles of each category in time T.

This regression analysis was done to all four junctions and found all regression coefficients for this five type of vehicle with statistical performance along with the y-intercept. The results were given in Table No 4-6, 4-7, 4-8 and 4-9 for all the intersections.

Table 4-6: Regression Coefficients for Borella Intersection

Variable	***Coefficient***	***Standard Error***	***T Stat***	***Model adjusted R Square***
Intercept	0			0.989
Three-wheeler	0.964	0.05940	16.23752	
Motorcycle	0.695	0.09166	7.57967	
Bus	3.291	0.13705	24.00996	
Large vehicle	2.694	0.14332	18.79735	
Car	1.473	0.02546	57.87681	

Table 4-7: Regression Coefficients for Dematagoda Intersection

Variable	***Coefficients***	***Standard Error***	***t Stat***	***Model adjusted R Square***
Intercept	0			0.954
Threewheeler	0.654	0.141	4.632	
Motorcycle	1.323	0.297	4.449	
Bus	2.896	0.706	4.099	
Large vehicle	2.935	0.423	6.932	
Car	1.395	0.086	16.174	

Table 4-8: Regression Coefficients for Senanayake Intersection

Variable	***Coefficients***	***Standard Error***	***t Stat***	***Model adjusted R Square***
Intercept	0			0.977
Three-wheeler	0.963	0.152	6.325	
Motorcycle	0.694	0.088	7.914	
Bus	2.452	0.478	5.126	
Large vehicle	2.825	0.366	7.726	
Car	1.412	0.026	53.300	

Table 4-9: Regression Coefficients for Palan thuna Intersection

Variable	***Coefficients***	***Standard Error***	***t Stat***	***Model adjusted R Square***
Intercept	0.000			0.958
Three-wheeler	1.133	0.155	7.324	
Motorcycle	0.580	0.223	1.253	
Bus	2.149	0.532	4.039	
Large vehicle	2.853	0.332	8.591	
Car	1.607	0.080	20.175	

After obtaining the Regression Coefficients, PCU factors were calculated by dividing coefficient of each vehicle category by coefficient of car.

Ex:

$$\text{PCU for Three-wheeler} = \frac{\text{Regression Coefficients of Three-wheeler}}{\text{Regression Coefficients of car}}$$

The results obtained for the PCU factors are given in Table No 4-10.

Table 4-10: Summery of PCU Factor Values Obtained in Regression Analysis and Vehicle Composition of Each Intersection

Intersection	**Parameter**	**Car**	**Three-wheeler**	**Motorcycle**	**Bus**	**Heavy Vehicle**
Borella	PCU Values	1.00	0.65	0.47	2.23	1.82
	% of vehicles	54.7%	22.9%	10.3%	6.5%	12.1%
Dematagoda	PCU Values	1.00	0.47	0.95	2.08	2.10
	% of vehicles	44.1%	35.3%	10.5%	3.6%	10.1%
Senanayake	PCU Values	1.00	0.68	0.49	1.73	2.0
	% of vehicles	68.9%	13.2%	12.4%	2.1%	5.5%
Palanthuna	PCU Values	1.00	0.70	0.36	1.33	1.78
	% of vehicles	52.6%	19.2%	16.7%	3.8%	15.4%

Form the above analysis it is clear that PCU factors are varying with the vehicle composition of the traffic stream. After obtaining the dynamic PCU factors, saturation flow calculated and given in Table No. 4-10.

Table 4-11: Summary of Saturation Flow Rate Values in veh/hr and pcu/hr

Intersection	**Saturation flow (Veh/hr/ln)**	**Saturation flow (pcu/hr/ln)**	
		(using available PCU Factors)	(PCU factors obtained from regression analysis)
Borella	2496	2553	2435
Dematagoda	2785	2716	2574
Senanayake	2705	2562	2516
Palan thuna	2626	2493	2313

Based on Table No 4-10, all the saturation flow rates in pcu/hr/ln is much lower than the observed saturation flow values in veh/hr/ln.

5. DISCUSSION

This study attempted to calculate the saturation flow rate in urban areas in Sri Lanka. This was mainly done by the collected data from four different intersections in Colombo. From the analysis, the mean headway was calculated and found to be in a range of 1.29 s – 1.45 s and consequently, the base saturation flow rate was found to be 2313 veh/hr/lane -2574 pcu/hr/lane. This result is significantly higher than the value suggested by HCM 2010 which is 1,900 pc/hr/ln and quite similar to those countries which having similar driver behavior and traffic environments. However the HCM 2010 also advices that the local traffic condition and driver behavior affect to the variation of saturation flow of a signalized intersection and therefore it should be measured and corrected at the local level. If not, it is underestimation of the signal timing and lead to traffic congestion in intersections. Therefore accurate determination of saturation flow for a given region is very important in signal timing design as it directly affects signal timing.

The vehicle type has a significant effect on the saturation flow rates. It is found that the saturation flow tends to increase with the increasing of three-wheelers and motorcycles due to heterogeneity and filling the gaps and saturation flow tends to decrease with the increment of car proportions due to more homogeneity. Further saturation flow tend to decrease with increasing the proportion of heavy vehicles due to slow movement and larger size. Therefore mix traffic condition play an important role of varying the saturation flow rate in signalized intersection in urban areas. The study clearly emphasize the need for estimation of PCU values based on actual field studies at signalized intersections. It was found that those PCU values are varying considerably in each intersections which having different geometric conditions, performance of vehicles and as well as composition of the vehicles. Therefore current PCU values used may not accurate to the capacity analysis in Sri Lanka.

The finding of this study resulted from analysing only four selected signalized intersections in Colombo. Prior to generalizing these results it is necessary to verify these results using a larger sample size and it will help to model the situation and obtain better correlations for the mixed traffic conditions.

6. CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

The correlation developed for saturation flow with vehicle types are based on the traffic environments at the selected signalized intersections for through movement and combined movement of through and turning movements. Even though separate right turn and left turn lanes were excluded for the study, lanes with sharing turning movements were considered. Therefore this can be developed further, for separate movements as through (TH) and right (RT) turning traffic separately. From this kind of comprehensive data, it can be established reliable model for general application for varying vehicle compositions.

Another important fact which was came a cross in this study is the varying traffic composition in different intersections. It will generalize as composition of vehicles are varying with area-wise. In some urban areas we also encountered that more three-wheelers than other vehicles. Therefore when analysing data, it can be developed traffic models for area basis, if we collected more data for those intersections. In that point of view we can use those models when implementing signalizing in such intersections in future.

Number of lanes of an intersection leg can be another variation factor of the saturation flow, even the saturation flow was calculated in lane basis. In current study two lane and three lane intersections were used for the analysis. It is noticed some deviations between those intersections. Therefore geometric condition as number of lane can be considered for the future works and can be use exactly same lane arrangement to examine the actual pattern of saturation flow. Vehicles which does not follow the lane and as well as motorcycles which gathered in front of queues did not used for the calculation of saturation flow in this study and there can be an effect on the saturation flow. Therefore it is recommended to address this issue in future studies.

This study can be used as a baseline for further studies on analysis of traffic flow at signalized intersection in Sri Lanka to further development of traffic models with relationship between saturation flow and proportion of different type vehicles. From that it will ensure the accurate capacity analysis for signal time calculations in future and it will match with the local traffic conditions in urban areas.

7. REFERENCES

Adams, C.A., Zambang, M.A.M., & Opoku, R. (2015). Effects of motorcycles on saturation flow rates of mixed traffic at signalized intersection in Ghana, *International Journal of Traffic and Transportation Engineering, 4*(3), 94-101.

Alam, M.J.B., Osra, K.A., Al-Bar, H.O., & Zahran, S.Z. (2011). Signalized intersection capacity adjustment factors for Makkah, Saudi Arabia. *Canadian Journal of Transportation, 4*(1).

Bester, C.J., & Meyers, W.L. (2007). Saturation flow rates. *Proc. 26th Southern African Transport Conference,* Pretoria, South Africa.

Bester, C.J., & Varndell, P.J., (2002). The effect of a leading green phase on the start-up lost time of opposing vehicles. *South African Transport Conference*, Pretoria, South Africa.

Branston, D.M. (1977). Some factors affecting the capacity of signalized intersections. *Traffic Engineering and Control, 20* (August/September), pp.390-396.

Branston, D., & Gipps, P. (1981). Some experiences with a multiple regression method of estimating parameters at the traffic departure process. *Transportation Research, 6A*, pp. 445-458.

Dunlap, B.M. (2005). *Field measurement of ideal saturation flow rate from the highway capacity manual*. Master Thesis, Department of Civil Eng., University of West Virginia, Morgantown, West Virginia.

Greenshields. B.D., Shapiro, D., & Ericksen, E.L. (1947). *Traffic performances at urban intersections* (Technical Report No. 1). Bureau of Highway Traffic, Yale University.

Hadiuzzaman, M., Rahman, M.M., & Karim, M.A. (2008). Saturation flow model at signalized intersection for non-lane based traffic. *Canadian Journal of Transportation 2*(1).

Hamad, K., & Abuhamda, H. (2015). Estimating base saturation flow rate for selected signalized intersections in Doha, Qatar, *Journal of Traffic and Logistics Engineering 3*(1). Retrieved from http://www.jtle.net/uploadfile/2015/0826/20150826021325831.pdf

Holroyd, E.M. (1963). Effect of motorcycles and pedal cycles on saturation flow at traffic signals. *Road and Road Construction, 41*, pp. 315-316.

Hounsell, N.B. (1989). *The design and performance of signal controlled intersections*. Ph.D. thesis, Department of Civil Engineering, University of Southampton.

Leong, L.V. (2004). *A study on saturation flow rates of through vehicles at signalized intersections based on Malaysian road conditions*. Ph.D. thesis, University of Sains, Malasia.

Mukwaya, R., Mwesige, G. (2012). Saturation flow rate for through traffic at signalized junction in Kampala. *Proc. Second International Conference on Advances in Engineering and Technology*, Kampala, Uganda.

Rahman, M.M., Ahmed S.N., & Hassan, T. (2005). Comparison of saturation flow rate at signalized intersection in Yokohama and Dhaka. *Proceeding of the Eastern Asia Society for Transportation Studies. vol. 5*, pp. 959-966.

Shao, C.Q., Rong J., & Liu, X.M. (2011). Study on the saturation flow rate and its influence factors at signalized intersections at China, *Procedia Social and Behavioral Sciences 16*, 504-514. Retrieves from https://ac.els-cdn.com/S1877042811010172/1-s2.0-S1877042811010172-main.pdf?_tid=53586486-f517-11e7-aa8a 00000aab0f02&acdnat=1515486799_bfae009677b38c890719832054ed3bbd

Transport and Road Research Laboratory. (1963). *A Method of Measuring Saturation Flow at Traffic Signals*. Road Note No 34, London.

Transportation Research Board. (2000). *Highway Capacity Manual 2000*. National Research Council, Washington, D.C.

Transportation Research Board. (2016). *Highway Capacity Manual 2016*. National Research Council, Washington, D.C.

Tuner, J., & harahap, G. (1993). Simplified saturation flow data collection methods. Transport Research Laboratory, Crowthorne, pp. 1292-1293.