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Estimation of Motorcycle Equivalent Unit Using Multiple Linear Regression and Impact of Motorcycle on Saturation Flow Rates

(A case study of intersections of Kathmandu valley)

by

Pawan Neupane

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The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Estimation of Motorcycle Equivalent Unit Using Multiple Linear Regression and Impact of Motorcycle on Saturation Flow Rates (A case study of intersections of Kathmandu valley)**" submitted by Pawan Neupane in partial fulfillment of the requirements for the degree of Master in Transportation Engineering.

Supervisor: Anil Marsani
Assistant Professor
Pulchowk Campus, Nepal

External Examiner: Pradeep Kumar Shrestha, Ph.D.
Assistant Professor
Pulchowk Campus, Nepal

Committee Chairperson: Anil Marsani
Programme Coordinator
M.Sc. in Transportation Engineering
Department of Civil Engineering

Date: February, 2020

ABSTRACT

Kathmandu valley’s traffic is dominated by two-wheeler. The equivalence unit as suggested by Nepal Road Standards, 2070 is same for urban as well as rural roads. Unstable queue formation during peak hours is a common phenomenon of intersections in the valley. Since, Passenger Car Equivalence has been in used in countries where traffic is dominated by cars, the need for Motorcycle Equivalence Unit is obvious for the traffic stream hugely populated with motorized two- wheelers. Relevant information regarding headway and saturation flow can only be obtained from using dominating mode of transportation as a standard vehicle.

The study of eight different intersections of Kathmandu valley was conducted with the help of recorded videos of vehicular movement in through and right turning direction. Multiple linear regression technique was used to calibrate motorcycle equivalent units using “R” database software. This study deduces that Nepal Road Standards, 2070’s Passenger Car Unit values of various group of vehicles is not applicable for urban intersections of Kathmandu valley. The average headway for through traffic is 0.47 second and for right turning traffic is 0.56 second. The saturation flow rate for through vehicles is 7,625 motorcycles per hour per lane and right turning vehicles is 6,492 motorcycles per hour per lane. This study also shows that the increase in proportion of two-wheelers in traffic stream decreases headway whereby increasing saturation flow rate.

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LIST OF ACRONYMS AND ABBREVIATIONS

DoTM:	Department of Transport Management
HCM:	Highway Capacity Manual
JICA:	Japan International Cooperation Agency
MEU:	Motorcycle Equivalence Unit
MoPIT:	Ministry of Physical Infrastructure and Transportation
NRS:	Nepal Road Standards
PCE:	Passenger Car Equivalence
PCU:	Passenger Car Unit
TRRL:	Transport and Road Research Laboratory

CHAPTER ONE : INTRODUCTION

1.1 Background

Passenger Car Equivalent (PCE) was first introduced by Highway Capacity Manual in 1965 A.D. to account for the impact of heavy vehicles in traffic stream of America. However, dominance of two-wheeler in the traffic stream is major characteristics of urban centers of under developed countries. The major challenges of traffic in some Asian countries is significantly higher proportion of two-wheeler traffic (Le & Nurhidayati, 2016).According to vehicle registration data published by Department of Transport Management (DoTM), Nepal, 78.5 % of total vehicle (32,21,042) registered in Nepal till end of fiscal year 2074/2075 B.S. is two-wheeler. In Kathmandu like city, Bangalore demonstrated 70% of transportation modes dominated by two wheelers (Anusha, Verma, & Kautha, 2012). The travel mode share study, (MoPIT;JICA, 2012) showed increase of motorcycle as a mode of transportation from 9.3% in 1991 A.D. to 26% in 2011 A.D. Leaving walking as a mode of transportation, two wheelers share nearly 44% of travel modes. The trend is increasing as the registered motorcycle is increasing in Kathmandu valley. Being auto oriented country, car equivalence might have been the standard of choice for America, whereas for the traffic composition dominated by two-wheelers of Kathmandu valley, Motorcycle Equivalent Unit is the obvious standard of choice.

Development of unstable queue of vehicles in major intersections during peak hour is a day to day phenomenon of traffic in Kathmandu valley. Affordability, mobility and accessibility are the major three criteria for dominance of motorcycle in the street. Motorcycle traffic significantly alters operational characteristics of other modes forcing to reduce speed and alter congestion. Both side overtaking maneuver is a common attribute of motorcycle in Kathmandu valley because of which motorcycle may use every space of roadway. The study of effect of proportion of two-wheelers in saturation flow is essential.

1.2 Statement of problem

Equivalence of any vehicle category in terms of some standard vehicle can be generated through various techniques. The techniques namely homogenization coefficient, semi empirical method, headway method, walker’s method, simulation method and multiple linear regression method. All these methods however employ speed, space and time directly or indirectly. Unlike most cities of developed nations where traffic is predominantly auto-oriented, cities of underdeveloped countries like Nepal are flooded with two wheelers. Since, car dominates the street and highways of developed countries, Passenger Car Unit (PCU) is used as standard for homogenization of traffic study. Two-wheelers, being the major share-holder of traffic on the under developed countries, Motorcycle Equivalent Unit (MEU) is used here in this study. The absence of proper lane discipline, hinders use of headway method for study of equivalent standard unit and supports use of multiple linear regression technique.

The data published by DoTM shows 104,444 registered motorcycles in the year 2074/2075 for Bagmati district. This sharp increase in ownership of vehicles in Kathmandu valley has led traffic management, a serious problem for the concerned authority and public. Travel time delay due to congestion is a common phenomenon. Passenger Car Unit (PCU) given by Nepal Road Standards 2070 (NRS, 2070) is same for urban centers, rural highways and any roads elsewhere. The PCU is hence not suitable for calculation of saturation flow and capacity in the roads of urban centers. This study will be help for the estimation of saturation flow of intersections of Kathmandu valley and hence helps in signal optimization.

1.3 Research question

The research questions this study is trying to find are as follows

1. What are the equivalences of classified types of vehicles on the standard of two-wheeler?
2. Is NRS correctly evaluating passenger car unit?
3. What is the saturation flow at any intersection?
4. What is effect of proportion of two-wheelers on saturation flow?

1.4 Objectives of study

The main objective of this study is to find effect of motorcycle on saturation flow and capacity of urban roads, through development of successful equivalence model of traffic volume estimation for intersections which is, dominated by two wheelers and, non-compliant to strict lane discipline.

The specific objectives of this study are as:

1. To generate equivalent unit of classified vehicle group based upon two-wheeler.

2. To compare existing standard units (NRS,2070)
3. To calculate headway and saturation flow of a lane in intersection.
4. To study effect of proportion of two-wheelers on saturation flow.

1.5 Scope of study

This study aims to focus on some of the busiest intersections of Kathmandu valley namely, Thapathali intersection, Keshar mahal intersection, Baneshwor intersection, Kalimati intersection, Chabahil intersection, Maharajgunj intersection, Gaushala intersection and Koteshwor intersection. The former four intersections lie inside ring road whereas the later four are the part of ring road. Traffic congestion are seen more often in these intersections.

The scope of this study are as:

1. Calibration of MEU of classified vehicle group.
2. Determination of headway and saturation flow of vehicles.

1.6 Limitation of study

The major limitations of this study are as:

1. Non-compliance to lane discipline forced to calculate imaginary headway (since, number of motorcycles are high and spatially staggered)
2. Non-motorized two-wheeler infiltrated at the beginning of queue and were not significant and hence any observed were included in two-wheeler motorized vehicle group.
3. The saturation flow time period was based on manual observation.

1.7 Organization of the report

This study report comprises of five chapters. This current chapter gives scenario of problem with general introduction and objectives of the study. The second chapter briefly describes literatures associated with equivalence units. The third chapter comprises of study area and methodology adopted for this study. The fourth chapter discusses results of this study and comparison with Nepal standards and previous studies. The fifth chapter summarizes the results and recommends topics for further study.

CHAPTER TWO : LITERATURE REVIEW

The study of traffic can be broadly categorized in two group microscopic approach and macroscopic approach. The microscopic approach of study deals with interaction of vehicle with other vehicles and environment whereas macroscopic approach deals with the flow of traffic stream. Car following model is an example of microscopic approach of study. The major component of traffic stream flow are speed, flow and density.

2.1 Speed

Simply, speed is distance covered per unit time. In traffic flow, speed is a direct indicator of traffic stream pattern and geometrics of the road. The two speed derivatives, fancied for traffic study are time mean speed and space mean speed. Time mean speed is mean speed of all the vehicles passing a point in road section over time and space mean speed is average speed of vehicles in traffic stream over some specified period of time. The units are meter per second and kilometer per hour.

2.2 Flow

Flow or volume is the number of vehicles that pass a point in a road section during specified time interval. Volume is simply the ratio of total number of vehicles passing a particular point in a certain time to that time. The unit of volume is number of vehicles per hour. Volume measurement can be of several types. Mathematically,

$$Q = N/T$$

Where, Q = Flow or volume (vehicles/time)

N = Number of vehicles

T = Time interval

2.3 Density

Density is defined as total number of vehicles occupying a particular section of road. It is often expressed as number of vehicles per kilometer. Mathematically, density

$$K = N / L$$

Where, K = Density (vehicles/length)

N = Number of vehicles occupying the specified section

L = Length of section.

2.4 Headway

Headway or spacing can be defined in terms of both time and space and these two are two types of headway. Time headway is the time in seconds between two successive vehicles as they pass through a point on road section. Space headway is the distance between the common features of successively travelling vehicles at any road section. For example, front to front or rear to rear.

2.5 Capacity

The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions as per Highway Capacity Manual (HCM, 2010). The maximum number of vehicles that can pass within certain time interval is defined as vehicle capacity.

2.6 Standard vehicle equivalence

The term passenger car equivalent (PCE) was first introduced in Highway Capacity Manual in 1965 to account for the impact of heavy vehicles on traffic stream. Various methods have since evolved for calibration of passenger car equivalent.

Generally, Passenger Car Unit (PCU) has been adopted as standard method of converting different type of vehicle into equivalent single class of vehicle. Standard vehicle equivalence can be described as the ratio of capacity of road with that only class of vehicles in the road to that of capacity with standard vehicles only. Basically, these standardization unit use some derivative form of area and space required for vehicles, its speed and interaction with other vehicles with due consideration of proportion.

2.6.1 Flow rate and density method

Passenger car equivalence (HCM, 2010), calculates PCE based upon flow rates, density and speed. Huber (1982) proposed a model for estimating PCE values for vehicles in multilane conditions under free-flowing condition. His method used the volumes of two streams at some common level of impedance with proportion of truck. PCE is calculated as

$$PCE = \frac{1}{P_T}\left(\frac{q_B}{q_M} - 1\right) + 1$$

Where,

PCE = Passenger Car Equivalent

P_T= proportion of truck in mixed flow

q_B= passenger car equivalent of only car condition for given v/c ratio

q_M= mixed flow rate

Sumner et al. (1984) upgraded Huber's method to incorporate more than one truck type in the traffic stream.

$$PCE = \frac{1}{\nabla P}\left(\frac{q_B}{q_s} - \frac{q_B}{q_M}\right) + 1$$

Where,

q_s= additional subject flow rate

∇P= proportion of subject vehicles

Demarchi and Setti ((Demarchi & Setti, 2003)) stated upgraded this method to eliminate the possible error for mixed heavy vehicles in traffic stream, including interactions between multiple truck types:

$$PCE = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1$$

Where,

P_i= proportion of trucks of type I out of all trucks n in the mixed traffic flow.

2.6.2 Headways method

The concept of headway utilizes headway as a measure of space occupied by a vehicle. This is common method of PCE estimation at signalized intersections. Greenshields et al. (Greenshields, Schapro, & Ericksen, 1947) employed headway ratio method at the most basic form and is as:

$$PCU_i = \frac{H_i}{H_c}$$

Where,

H_i= average headway of i vehicle type,

H_c= average headway of passenger car

Later researchers in this field used some sort of variation of this basic formula to derive PCE values. The variations include proportions of cars and proportions of trucks. Furthermore, conditional approach of one vehicle following the other vehicle type was utilized for calculation of PCEs.

Subedi (Subedi, 2016) took into consideration nine different types of vehicles over three different intersections to calculate PCU values of the classified group of vehicles over three intersections Maharajgunj, Balkhu and Baneshwor intersections. He used headway method of calculation of passenger car equivalence i.e., the ratio between time headway of "i" type vehicle to the time headway of passenger car. The values of PCU derived as average are shown in Table 2-1.

Table 2-1: PCU values calculated by Subedi,

S.N.	Vehicle type	PCU
1	Car	1
2	Motorcycle	0.44
3	Truck	2.91
4	Mini Truck	1.45
5	Bus	2.93
6	Mini-Bus	2.15
7	Micro-Bus	1.32
8	Utility vehicle	1.11
9	Tempo	0.88

2.6.3 Speed method

Chandra and Sikdar (Chandra & Kumar, Effect of lane width on capacity under mixed traffic conditions in India, 2003) stated a methodology to estimate PCE values by using vehicle area and speed. The formula states as

$$PCU_i = \frac{V_c/V_i}{A_c/A_i}$$

Where,

V_c= mean speeds of car

V_i=mean speeds of i vehicle type

A_c= projected rectangular area of car

A_i=projected rectangular area of i vehicle type

Rahman and Nakamura (Rahman & Makamura, 2005) proposed unit value plus the ratio of speed difference of passenger cars in basic flow and mixed flow to the speed of passenger cars in basic flow to calculate the PCE of non-motorized vehicle (rickshaws) in Dhaka.

$$PCU_{nmv} = 1 + \frac{S_b - S_m}{S_b}$$

PCU_{nmv}= Passenger car equivalents of non-motorized vehicles

S_b= Average speed of passenger car in the basic flow (km/hr)

S_m=Average speed of passenger car in the basic flow (km/hr)

Shrestha (Shrestha A. K., 2016) in his research study calculated motorcycle equivalent in road section of Kathmandu valley namely,

- Old Bus-park
- Shital Niwas
- Kalimati

His study proposed MEU values: as presented in Table 2-2.

Table 2-2: MEU values from Shrestha, (Shrestha A. K., 2016).

Section	MEU for Vehicle type				
	Cycle	Motorcycle	Car	Mini bus	Bus
1	1.46	1	5.29	13.22	27.1
2	1.35	1	5.21	12.61	26.32
3	1.08	1	4.92	12.6	26.49

His calculation yielded headway as presented in Table 2-3.

Table 2-3: Headway of vehicles from study of Shrestha, (Shrestha A. K., 2016).

Location	Motorcycle Volume	Number of sampling	Observed headway				
			Mean (s)	Max (s)	Min (s)	St. dev.	
						(s)	%
1	4155	400	1.56	5.45	0.32	1.08	69
2	2277	225	1.94	5.49	0.35	1.39	71
3	1805	173	1.89	5.35	0.37	1.17	61

2.6.4 Multiple linear regression method

Multiple linear regression technique can be used to calculate passenger equivalence. Van Aerde and Yagar ((Aerde & Yagar, 1984)) developed a model based on speed reduction coefficients. The speed analysis using multiple linear regression based on volume of vehicles is based upon the following relations.

$$PCU_i = free\ speed + C_1(number\ of\ passenger\ cars)$$
$$+ C_2(number\ of\ trucks)$$
$$+ C_3(number\ of\ RVs)$$
$$+ C_4(number\ of\ other\ vehicles)$$
$$+ C_5(number\ of\ opposing\ vehicles$$

Where,

C_1= coefficients of passenger cars

C_2= coefficients of trucks

C_3= coefficients of RVs

C_4= coefficients of other vehicles

C_5= coefficients of opposing vehicles

The ratio of these coefficients with respect to coefficient of passenger car gives passenger car equivalent.

$$PCU_i = \frac{C_i}{C_1}$$

Branston and Gipps (Branston & Gipps, Some experience with a Multiple Linear Regression Method of Estimating Parameters of the Traffic Signal Departure Process, 1981) developed regression model to estimate passenger car equivalents. Their research used regression method of estimating saturation flow, effective green and PCU values on traffic signal approach. The study method divided green time to three periods. First period attributed to the time till the flow becomes saturated overcoming initial lag. Last period attributed to fall of traffic flow below saturation period.

Kimber et al (Kimber, McDonald, & Housnell, 1985) also utilized linear regression method to account for passenger car units in saturation flow and estimation of saturation at signalized intersection and their use and effectiveness respectively.

Charles et al (Adams, Zambang, & Boahen, 2015) studied effects of motorcycle on saturation flow rates of mixed traffic at signalized intersections in Ghana. The PCU values are based upon coefficients of different classes of vehicles regressed against total saturation interval of flow during effective green time. His general form of equation is as

$$t = a_0 + a_1 n_1 + a_2 n_2 + a_3 n_3 + a_4 n_4$$

Where,

t= effective saturation time interval

a_0= constant coefficient

a_1= coefficient of motorcycles

a_2= coefficient of tricycles

a_3= coefficient of cars/taxi

a_4=coefficients of buses/trucks

n_1= number of motorcycles

n_1= number of tricycles

n_3= number of cars/taxi

n_4= number of buses/trucks

The regression coefficients of various vehicle class obtained from this regression analysis was divided by car coefficient to obtain equivalent unit for various classes of vehicle.

$$PCU(Motorcycle) = \frac{a_1}{a_3}$$

$$PCU(Tricycle) = \frac{a_2}{a_3}$$

$$PCU(Bus/Truck) = \frac{a_4}{a_3}$$

The heterogeneous traffic condition gives rise to various headways, with motorcycle the most to frequently change lane. The headway in this case is rather imaginary and calculated for estimation of saturation flow.

$$H = \frac{t_s}{n_1 P_1 + n_2 P_2 + n_3 P_3 + n_4 P_4}$$

Where,

H= saturation headway

t_s=time of saturation flow of vehicles at intersection

P_1= PCU value of motorcycle

P_2= PCU value of tricycle

P_3= PCU value of car/taxi

P_4= PCU value of bus/truck

Shrestha (Shrestha S. , 2014) on her master's thesis research studied traffic flow at three intersection namely, Koteshwor, Tinkune and Jadibuti intersections. She employed multiple linear regression to calculate PCU values of car, truck, bus two-wheeler, micro-bus and tempo as shown in Table 2-4.

Table 2-4: PCU values (Shrestha S. , 2014).

PCU	Car	Truck	Bus	Two-Wheeler	Microbus	Tempo
Estimated Value	1	2.65	2.19	0.25	1.67	1.3

She used the regressed PCU to calculate saturation flow and employed saturation model depending upon width, length of green time of the approach, percentage of right turning vehicle, percentage of heavy vehicles and percentage of two wheelers in a forward regression pattern.

Ashish (2016) on his research study on effect of motorized two wheelers on saturation flow at signalized intersection in Jadibuti-Sallaghari road section of Araniko Highway eased by dividing vehicle into three classes as car, heavy vehicles and motorized two wheelers. He observed that two wheelers intercepted during red light at intersection and frequented more in beginning of cycle and the vehicle composition studied involved more than 70% of two wheelers. He calculated adjustment factor for motorized two wheelers using HCM-2000 method. The adjustment factor ranged from 1.070 to 1.298 and was averaged 1.22.

While, there are many alternatives to determine motorcycle equivalence unit for this study, multiple linear regression technique has been adopted because of the heterogenic traffic with non-compliance to lane discipline.

Different countries' and even states' of a same country employ different PCU values for standardization of other class of vehicles. Nepal road standards 2070 adapts PCU values as shown in Table 2-5: NRS PCU table

Table 2-5: NRS PCU table

Vehicle Type	**Adopted PCU Value**
Bicycle, Motorcycle	0.5
Car, Auto Rickshaw, SUV, Light Van and pick up	1
Light (Mini) Truck, Tractor, Rickshaw	1.5
Truck, Bus, Minibus, Tractor with trailer	3.0
Non-motorized carts	6

All the prevailing methods of measuring saturation flows assume saturation flow rate is fixed during saturated green signal. Headway method, regression method and Transport and Road Research laboratory (TRRL) method are commonly employed

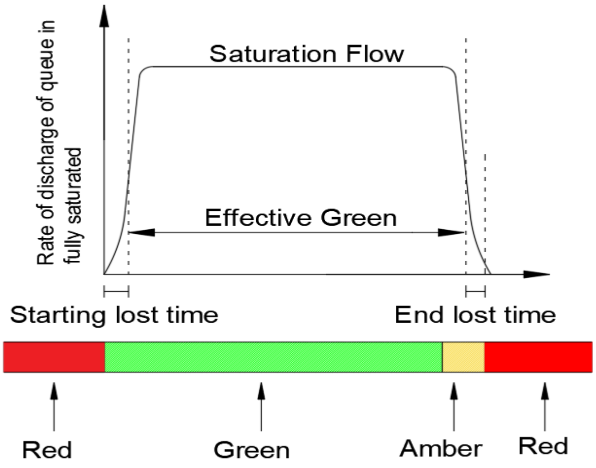

Figure 2-1: Saturation flow rate vs green time

methods for calculation of saturation flow rates. Headway method estimates average time headway between vehicles discharging from queue as they pass stop line. According to Highway capacity manual (HCM 2010) interrupted-flow facilities naturally operate from queue discharge conditions and hence flow on these facilities is equal to saturation flow rate which can be seen visually from Figure 2-1: saturation flow rate vs green time. As can be seen from Figure 2-2, of headway vs vehicle in queue, the initial head losses is skipped to avoid vehicle's internal friction during initial start-up period. The saturation flow rate is calculated as reciprocal of mean headway.

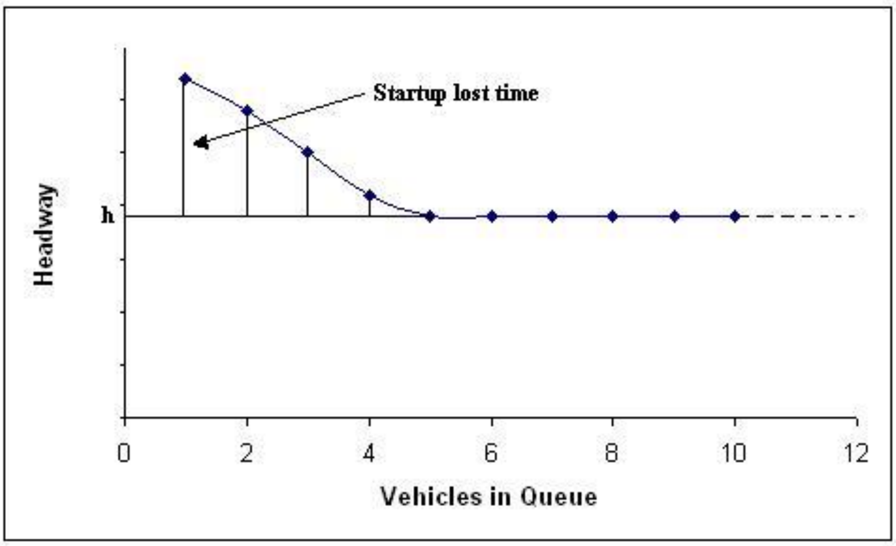

Figure 2-2: Headway vs vehicle in queue

Flow density and density method is used where flow is relatively free. Headway method is difficult to use because of staggered orientation, due to absence of lane discipline. During saturation flow vehicles will have more or less similar speed and the calculation will be generated by area ratio. Thus, following the various methods of calculation of equivalence units, multiple linear regression with motorcycle as standard vehicle is identified as suitable method because of heterogeneous traffic condition, non-compliance to lane discipline and high volume of motorized two-wheelers in the traffic stream.

CHAPTER THREE : METHODOLOGY

3.1 Research Process

This research study aims to find out motorcycle equivalent unit of classified group of vehicles and hence headway and saturation flow. The following flow chart is shown to depict process followed to achieve objective of this study.

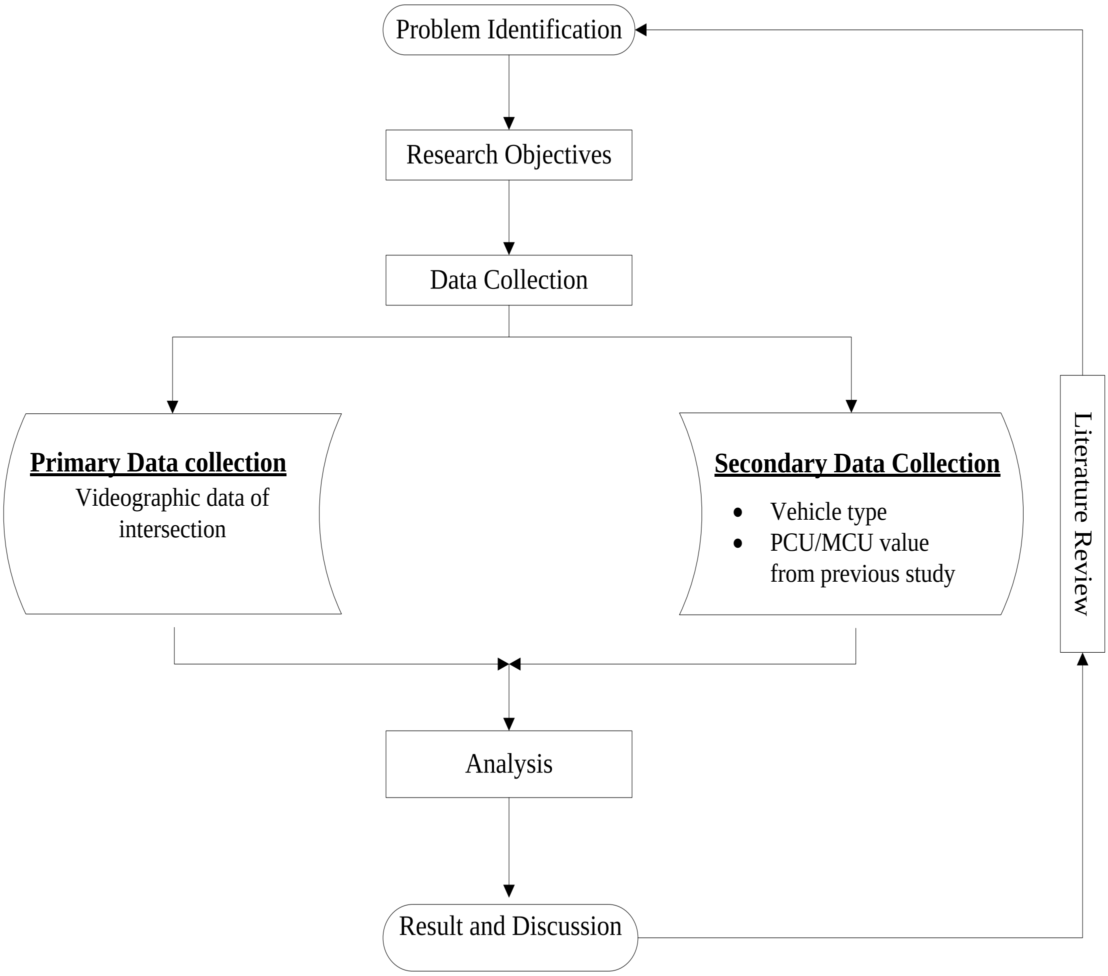

Figure 3-1: Flowchart of study methodology

Primarily, the problem is identified as the study of impact in saturation flow at an intersection. To calibrate the model for regression equation for determination of motorcycle equivalence unit video-graphic data was collected. Classified vehicle count of different intersections were performed. Similar study done beforehand in Nepal as well as elsewhere on the world were collected and compared. The flow chart of study methodology is as shown in Figure 3-1: Flowchart of study methodology.

3.2 Site Selection

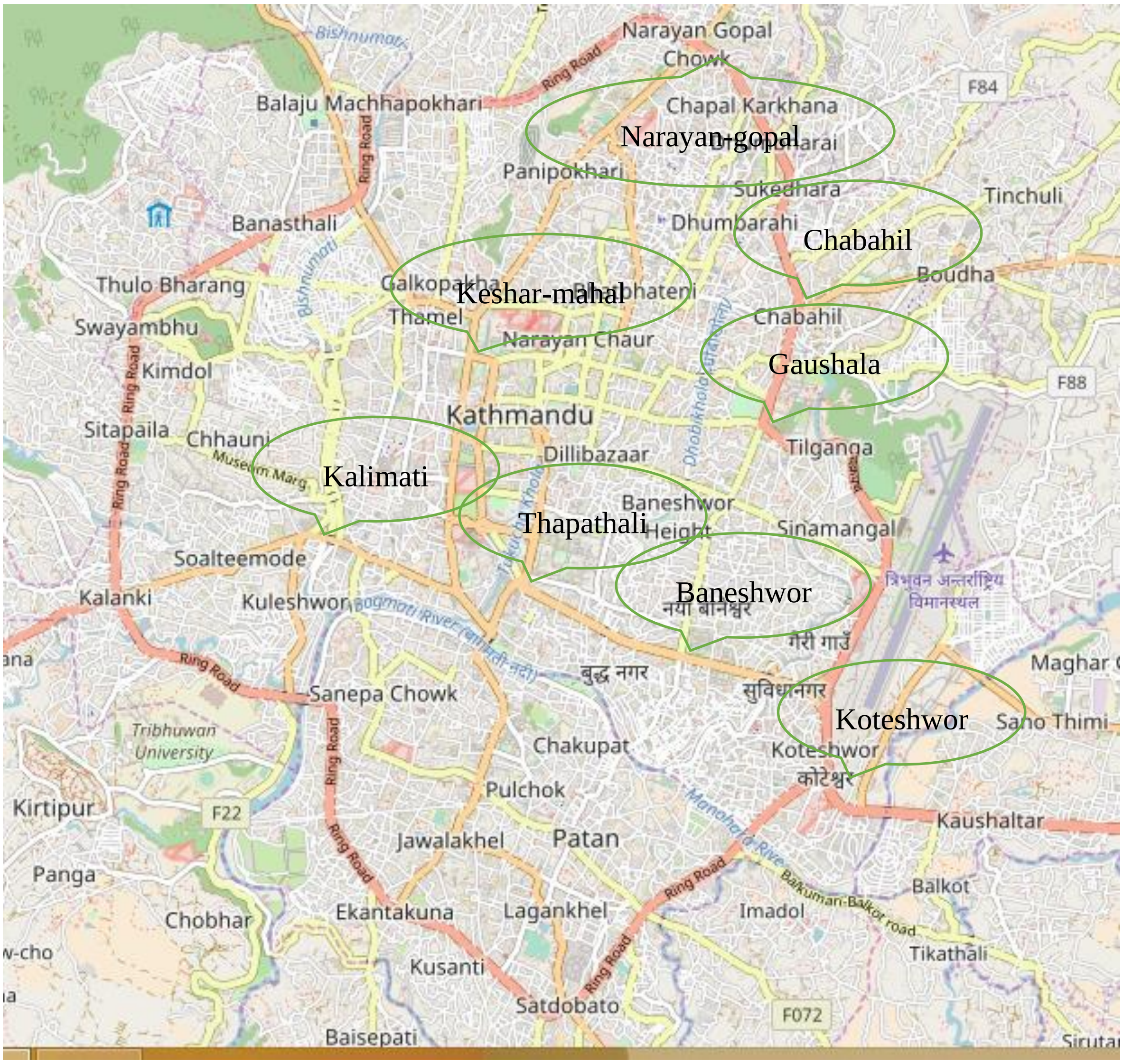

Figure 3-2: Overview of Kathmandu valley with study intersection

The objective of this study requires for the study of saturation flow and capacity of urban roads and intersections and hence some of the busiest intersection of Kathmandu valley (as evident from unstable queue formed during peak hours) were taken for the study purposes. After careful observations of queue formations and significant flow of vehicles, above 8 intersection as shown in Figure 3-2: Overview of Kathmandu valley with study intersection were selected which are listed as:

- **Thapathali intersection:** Thapathali intersection is one of the busiest intersections in Kathmandu valley. Geometrically this intersection is 4-legged intersection but functionally it is similar to 3-legged intersection with *Norvic* approach having the least of traffic flow. Traffic from *Kupondole* approach is considered for through traffic whereas traffic from *Tripureshwor* and *Maitighar* approach is considered for right turning traffic.

- **Baneshwor intersection:** This is a 4-legged intersection with major volumes from *Tinkune* and *Maitighar* approach. All four right turning movement has been considered for calibration of equivalent unit.
- **Kesharmahal intersection:** Kesharmahal intersection is also a busy intersection with unstable queue formation during peak hours of morning and evening. The queue has been notably observed in through movement of vehicles from *Lainchour* and *Jamal* approach. Right turning maneuver has been however considered for all four approaches.
- **Kalimati intersection:** Kalimati intersection is basically a 3-legged intersection. The through movement of this approach has been considered for traffic movements from *Kalanki* approach and right turning volume of traffic from *Balkhu* Approach.
- **Narayan Gopal intersection:** This is a 4-legged intersection situated at ring road of Kathmandu valley. Each approach has been considered for through as well as right turning traffic.
- **Koteshwor intersection:** This intersection is located at eastern part of Kathmandu ring road. The traffic from and to Bhaktapur as well as ring road is significant yielding in unstable queue formation at this location. The through movement of vehicles from *Jadibuti* has been considered for the calibration whereas both the movement from *Tinkune* and *Balkumari* approach has been considered for turning movement.
- **Chabahil intersection:** Chabahil intersection functions as a 3-legged intersection at the ring road of Kathmandu valley. The vehicular movement from *Narayan Gopal* approach has been considered for through movement whereas turning movements from Jorpati and Gaushala approach has been utilized for calibration procedure.
- **Gaushala intersection:** Gaushala is a 4-legged intersection in Kathmandu valley ring road. The traffic movement from each leg has been considered for through as well as right turning movement.

3.2 Data Collection Methodology

The major data collected for this study purpose was through video-graphic films. The geometric features of intersection were observed through direct site measurements and google maps. Various number of lanes was found in various direction of traffic flow. Majority of video-graphic films were obtained through surveillance camera of Nepal Police Division, Rani Pokhari. The cameras are rotatable and situated at enough height to monitor traffic in above mentioned intersection areas. The video-graphic films consisted of seven days peak hour traffic flow during morning and evening.

3.3 Data Extraction Methodology

The data obtained was simultaneously input on spreadsheet for further processing. Time of the commencement of traffic counting and ending were both included in spreadsheet. The different category of vehicles that would enter in the intersection was cut-off through an imaginary line on video-graphic film perpendicular to the direction of flow.

Since, the volume of bicycles was significantly low and they tended to intercept at the front of traffic, bicycle was categorized under two-wheeler. Non-motorized transportation was observed less frequent inside ring road of Kathmandu valley and hence was included in motorcycle.

3.4 Sampling size

The rule of thumb has been to use 10 to 20 cases for each independent variable. (Green, 1991) proposed two variation for consideration of dependent variable in multiple linear regression. He proposed minimum sample size to be greater or equal to 50+8 times number of independent variables. The sampling has been done based upon these two criteria i.e. more than 20 times number of independent variables. Since, 4 different independent variables were taken, sampling size for each intersection is taken above 80 samples.

3.5 Analysis Procedure

The classified volume data of different category of vehicles obtained through video-graphic film processing was used for analysis. ‘R’ is an open source programming language and software environment for statistical computing and graphics that is supported by R foundation for Statistical Computing (Wikipedia, 2017). This software R was used for analysis of data through multiple linear regression technique using a very small in-build function for calculation of coefficients of linear regression. The classified volume data was fed to R and the resulting coefficients were obtained.

The total saturated green time is regressed with number of different types of vehicles. Following equation shall be utilized to calculate coefficients of various classes of vehicles.

$$T = C + \sum A_i * N_i \text{ .... Eq. 1}$$

Where,

T = length of time when flow is saturated

C= Constant

A_i = Coefficient of i[th] vehicle group

N_i = Number of vehicles passing of i[th] vehicle group

Motorcycle equivalent unit of each vehicle group then shall be,

$$MCU_i = \frac{A_i}{A_m} \text{ .... Eq. 2}$$

Where,

MCU_i = Motorcycle equivalent unit of i[th] vehicle group

A_m = Regression coefficient of motorcycle

The saturation flow shall the be calculated as reciprocal of time headway,

$$S = \frac{3600}{H} pcu/hr$$

Where,

S = Saturation flow rate of vehicles.

H = Time headway of traffic stream and is given by,

$$H = \frac{T}{\sum MCU_i * N_i}$$

Where,

T = total saturation time of flow of traffic

CHAPTER FOUR : DATA ANALYSIS AND RESULTS

4.1 Vehicle Composition

Classified vehicle data on the basis of flow during saturation period is primary data of this research study. The time for this survey was taken to be morning (9:30 a.m.-11:00 a.m.) and evening (4:30 p.m.-6:30 p.m.) peak hours. The composition of vehicles is calculated on the basis of longer length of queue formation. The total volume of traffic for the total observed time for various legs are as shown on Table 4-1.

Table 4-1: Aggregated through vehicle composition

Intersections	Total Observed Time(sec)	Total Count of Vehicles							
		bike	taxi	car	Jeep	Micro	bus	truck	tempo
Baneshwor	2,589	2,860	139	414	130	33	18	13	11
Thapathali	2,357	2,355	130	368	78	86	73	12	39
Narayangopal	3,349	2,494	141	156	96	92	103	121	61
Kesharmahal	2,698	2,596	168	264	122	177	116	24	34
Koteshwor	2,573	1,845	90	162	72	70	96	75	45
Kalimati	3,046	3,240	149	192	115	152	90	68	18
Chabahil	2,229	1,848	75	150	60	77	75	39	39
Gaushala	1,993	1,656	85	134	50	69	61	39	28
Percentage Composition		**77.2 %**	**4%**	**7.5%**	**3%**	**3.09%**	**2.6%**	**1.6%**	**1.12%**

This aggregated volume of various class of vehicles shows clearly the dominance of two wheelers in traffic stream. The volume of taxi, car, jeep, micro and tempo is each individually less than 10% and since these have nearly similar characteristics like space and speed, were grouped into single category for the ease in calculations.

Right turning traffic volume is also integral part of this study. The total number of various group of vehicles for respective saturation flow period has been aggregated and presented in Table 4-2. To simplify the calculation of regression coefficient, the volume of car, jeep, taxi, micro and tempo are again compiled as car following similar size and speed. The volume of motorized two-wheelers placed in the group “bike” is again very high (79%) as compared to other vehicle groups.

Table 4-2: Aggregated right turning vehicle composition

Intersections	Total Observed Time (s)	Total Count of Vehicles							
		bike	Taxi	car	jeep	micro	bus	Truck	Tempo
Baneshwor	1,453	1,355	107	144	26	2	26	4	25
Thapathali	2,462	2,149	150	238	32	28	63	10	19
Narayangopal	2,461	1,634	87	99	72	85	85	49	25
Kesharmahal	2,483	2,179	149	238	33	28	63	10	2
Koteshwor	1,788	1,304	56	83	53	70	64	31	10
Kalimati	2,312	1,810	76	100	64	76	68	48	0
Chabahil	2,144	1,541	71	88	51	71	65	46	0
Gaushala	1,842	1,204	60	71	46	65	69	35	0
Percentage Composition		**79.32**	**4.6**	**6.39**	**2.3**	**2.56**	**3**	**1.4**	**0.488**

4.2 Motorcycle Equivalent unit

MEU is the measurement of the number of two-wheeler that would replace the desired vehicle under prevailing condition of traffic and environment. This calculation is necessary for standardizing calculation of saturation flow of the intersection. Since, the heterogenous traffic does not follow strict lane principle, this calculation of MEU will generate a pseudo headway for the flow which in turn will give the value of saturation flow.

For simplicity as well as similar operational characteristics observed in traffic stream; a group namely “Car” contained car, taxi, jeep micro and tempo. Similarly, “Bike” is group of two-wheeler traffic in the stream. This model regresses time against bike, car, truck and bus and yields coefficients. The coefficients and different statistical results are as shown below:

Through traffic at Thapathali:

The traffic volume considered for through traffic movement at Thapathali intersection comprises of traffic volume of the Kupandole – Maitighar approach since this approach is the only critical through movement approach as Norvic approach is not much operational. The calibration of coefficients and MEU is given in the Table 4-3.

Table 4-3: Calibration of through vehicles at Thapathali intersection

	Estimate	Std. Error	t-value	Pr (>|t|)	MEU value
(Intercept)	-0.63422	0.33975	-1.867	0.0642	
Bike	0.4473	0.01906	23.462	<2e-16	1
Car	1.57531	0.06206	25.385	<2e-16	3.52
Bus	3.32437	0.22323	14.892	<2e-16	7.43
Truck	3.46912	0.45995	7.542	7.28E-12	7.75

- Residual standard error: 1.511 on 129 degrees of freedom
- Multiple R-squared: 0.9632, Adjusted R-squared: 0.9621
- F-statistic: 844.3 on 4 and 129 DF, p-value: < 2.2e-16

This regression model is very much significant on basis of higher F-value and lower p-value and can predict nearly 96.2% of variation on time with the help of vehicle composition. The intercept of -0.6342 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. However, since evidently from p-value of intercept for each model, intercept can be deemed insignificant, as its value is very less as compared with time considered for model. A single car is equivalent to 3.52 motorcycles, whereas 7.43 motorcycles and 7.75 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.429 seconds and saturation flow is 8,378 motorcycles per hour per lane.

Through traffic at Baneshwor:

Through traffic at Baneshwor comprises of dominantly volume of Tinkune-Maitighar and Maitighar-Tinkune approach. The result of regression sis hsown in Table 4-4.

Table 4-4: Calibration of through vehicles at Baneshwor intersection

	Estimate	Std. Error	t-value	Pr (>|t|)	MEU value
(Intercept)	-0.49188	1.08653	-0.453	0.652	
Bike	0.47336	0.03774	12.542	<2e-16	1
Car	1.62366	0.11975	13.559	<2e-16	3.43
Bus	3.373	0.66566	5.067	1.48E-06	7.12
Truck	4.27364	0.8025	5.325	4.77E-07	9.03

- Residual standard error: 2.537 on 120 degrees of freedom
- Multiple R-squared: 0.7842, Adjusted R-squared: 0.777
- F-statistic: 109 on 4 and 120 DF, p-value: < 2.2e-16

This regression model is very much significant on basis of higher F-value and lower p-value and can predict nearly 77% of variation on time with the help of vehicle composition. The adjusted R-value in this scenario is quite lower as compared to other, which may be due to size of intersection and partial obstruction by right turning vehicles (spill back effect). The intercept of -0.4918 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.43 motorcycles, whereas 7.12 motorcycles and 9.03 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.462 seconds and saturation flow is 7,795 motorcycles per hour per lane.

Through traffic at Kesharmahal:

Kesharmahal through traffic is analogous to Baneshwor intersection as Jamal-Lainchaur and Lainchaur Jamal approaches tend for significant amount of through traffic. The calibration of coefficients and MEU is given in Table 4-5.

Table 4-5: Calibration of through vehicles at Kesharmahal intersection

	Estimate	Std. Error	t-value	Pr(>|t|)	MEU value
(Intercept)	-0.74664	0.52535	-1.421	0.158	
Bike	0.4621	0.01216	38	<2e-16	1
Car	1.48421	0.07548	19.665	<2e-16	3.21
Bus	3.23811	0.15874	20.398	<2e-16	7.00
Truck	3.01947	0.27433	11.007	<2e-16	6.53

- Residual standard error: 1.124 on 109 degrees of freedom
- Multiple R-squared: 0.9741, Adjusted R-squared: 0.9732
- F-statistic: 1026 on 4 and 109 DF, p-value: < 2.2e-16

This regression model is very much significant on basis of higher F-value and lower p-value and can account nearly 97% of variation in time of saturation flow. A single car is found to be equivalent to 3.21 motorcycles, whereas 7 motorcycles and 6.53 motorcycles are equivalent to a single bus and single truck respectively. A larger value of equivalence unit for truck rather than bus can be attributed to larger number of water tankers counted in truck group of this intersection. The water tankers were smaller in size and faster than other trucks. The average time headway for motorcycle is 0.424 seconds and saturation flow is 8,424 motorcycles per hour per lane.

Through traffic at Chabahil:

The ring road approach has significant through turning traffic and hence this approach has been selected for calibration of coefficient and MEU value. The calibration of coefficients and MEU is given in Table 4-6.

Table 4-6: Calibration of through vehicles at Chabahil intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	0.37638	0.50878	0.74	0.461	
Bike	0.52064	0.0228	22.84	<2e-16	1
Car	1.70373	0.09876	17.25	<2e-16	3.27
Bus	4.72335	0.26707	17.69	<2e-16	9.07
Truck	4.80132	0.2747	17.48	<2e-16	9.22

- Residual standard error: 1.376 on 107 degrees of freedom
- Multiple R-squared: 0.9426, Adjusted R-squared: 0.9405
- F-statistic: 439.5 on 4 and 107 DF, p-value: < 2.2e-16

This model is successful to estimate approximately 94% of variations in time in saturated traffic stream at Chabahil intersection with respect to flow of different vehicle composition. The intercept of 0.376 signifies, that during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow, ignoring initial head loss. A single car is found equivalent of 3.27 motorcycles, whereas 9.07 motorcycles and 9.22 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.532 seconds and saturation flow is 6,765 motorcycles per hour per lane.

Through traffic at Gaushala:

Through traffic at Gaushala mainly comprised of Mid-Baneshwor-Gaushala approach and Gaushala-Mid-Baneshwor approach. The calibration of coefficients and MEU is given in the Table 4-7.

Table 4-7: Calibration of through vehicles at Gaushala intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	0.20957	0.50205	0.417	0.677	
Bike	0.49686	0.02402	20.683	<2e-16	1
Car	1.9026	0.10026	18.977	<2e-16	3.83
Bus	4.44751	0.27506	16.169	<2e-16	8.95
Truck	4.65091	0.27548	16.883	<2e-16	9.36

- Residual standard error: 1.343 on 96 degrees of freedom
- Multiple R-squared: 0.9492, Adjusted R-squared: 0.9471
- F-statistic: 448.5 on 4 and 96 DF, p-value: < 2.2e-16

This model can predict the time required to pass various classes of vehicles in straight direction of traffic stream in Gaushala intersection with probability greater than 94%. The intercept of 0.496 signifies, that during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow, ignoring initial head loss. The equivalence of a single car is 3.83 motorcycles, whereas 8.95 motorcycles and 9.36 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.655 seconds and saturation flow is 5,492 motorcycles per hour per lane.

Through traffic at Kalimati intersection:

Kalimati intersection is a 3 -legged intersection. Through traffic volume considered for this study of through vehicle at this intersection comprises major volume of traffic from Teku-Kalanki approach and minor volume of Kalanki-Teku approach. The calibration of coefficients and MEU is given in Table 4-8.

Table 4-8: Calibration of through vehicles at Kalimati intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	-1.09519	0.6236	-1.756	0.0816	
Bike	0.4891	0.01954	25.032	<2e-16	1
Car	1.64161	0.05942	27.627	<2e-16	3.35
Bus	3.40505	0.23513	14.481	<2e-16	6.96
Truck	3.89988	0.22074	17.667	<2e-16	7.97

- Residual standard error: 1.221 on 121 degrees of freedom
- Multiple R-squared: 0.9518, Adjusted R-squared: 0.9502
- F-statistic: 597 on 4 and 121 DF, p-value: < 2.2e-16

The time required to clear through vehicles from Kalimati intersection can be successfully estimated from this model with success rate of over 95%. The intercept of -1.095 signifies that, during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow, ignoring initial head loss. A single car is equivalent to 3.35 motorcycles for this intersection, whereas 6.96 motorcycles and 7.97 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.557 seconds and saturation flow is 6,457 motorcycles per hour per lane.

Through traffic at Koteshwor:

Koteshwor intersection is functionally a 3-legged intersection. Through traffic at Koteshwor mainly comprised of Jadibuti-Tinkune approach and Tinkune-Jadibuti approach. The calibration of coefficients and MEU is given in Table 4-9.

Table 4-9: Calibration of through vehicles at Koteshwor intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	0.47255	0.46949	1.007	0.316	
Bike	0.44908	0.02576	17.436	<2e-16	1
Car	1.9842	0.10103	19.641	<2e-16	4.42
Bus	4.54973	0.23317	19.513	<2e-16	10.13
Truck	5.11583	0.24767	20.656	<2e-16	11.39

- Residual standard error: 1.357 on 107 degrees of freedom
- Multiple R-squared: 0.9638, Adjusted R-squared: 0.9624
- F-statistic: 711.5 on 4 and 107 DF, p-value: < 2.2e-16

The value of t-value greater than 1 and very small p-value suggests that this model successfully predicts time required to clear vehicles from Koteshwor intersection in through direction with reliability more than 96%. The intercept of 0.449 signifies that during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 4.42 motorcycles, whereas 10.13 motorcycles and 11.39 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.460 seconds and saturation flow is 7,823 motorcycles per hour per lane.

Through traffic at Narayan Gopal intersection:

All four through approach has been considered for calibration of coefficients and MEU values for Narayan Gopal intersection, the result of which are given below.

Table 4-10: Calibration of through vehicles at Narayan Gopal intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	-0.36829	0.43917	-0.839	0.404	
Bike	0.50582	0.01961	25.792	<2e-16	1
Car	1.9109	0.08035	23.781	<2e-16	3.77
Bus	4.79261	0.20515	23.362	<2e-16	9.47
Truck	4.89946	0.18903	25.92	<2e-16	9.68

- Residual standard error: 1.239 on 110 degrees of freedom
- Multiple R-squared: 0.9797, Adjusted R-squared: 0.979
- F-statistic: 1327 on 4 and 110 DF, p-value: < 2.2e-16

This model can predict the time required to pass various classes of vehicles in straight direction of traffic stream in Gaushala intersection with probability greater than 97%. The intercept of -0.368 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. 3.77 motorcycles are equivalent to a single car, whereas 9.47 motorcycles and 9.68 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.498 seconds and saturation flow is 7219 motorcycles per hour per lane.

The right turning vehicles are integral part of this research and hence their data in the respective section are given below:

Right turning vehicle at Baneshwor intersection:

All four right turning traffic has been considered for calibration of MEU values and coefficients at Baneshwor intersection. The result of calibration is presented in Table 4-11.

Table 4-11: Calibration of right turning vehicle at Baneshwor intersection

	Estimate	Std. Error	t-value	Pr(>|t|)	MEU value
(Intercept)	2.40121	0.35382	6.787	5.89E-10	
Bike	0.43823	0.02114	20.726	<2e-16	1
Car	1.70063	0.10115	16.813	<2e-16	3.88
Bus	3.4494	0.21268	16.219	<2e-16	7.87
Truck	4.12406	0.55439	7.439	2.29E-11	9.41

- Residual standard error: 1.07 on 111 degrees of freedom
- Multiple R-squared: 0.8967, Adjusted R-squared: 0.8929
- F-statistic: 240.8 on 4 and 111 DF, p-value: < 2.2e-16

This model successfully explains 89% of times the variation of time of saturation flow with respect to different vehicle compositions in traffic stream. The intercept of 0.438 signifies that during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.88 motorcycles, whereas 7.87 motorcycles and 9.41 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.551 seconds and saturation flow is 6,532 motorcycles per hour per lane.

Right turning vehicle at Kesharmahal intersection

Right turning volume at Kesharmahal intersection comprises data mainly of Durbarmarg-Lainchaur approach. Other approaches were minorly involved in calibration of coefficients and MEU value. The result is shown in Table 4-12.

Table 4-12: Calibration of right turning vehicle at Kesharmahal intersection

	Estimate	Std. Error	t-value	Pr(>|t|)	MEU value
(Intercept)	0.27718	0.43293	0.64	0.523	
Bike	0.51078	0.02468	20.698	<2e-16	1
Car	1.90444	0.11852	16.069	<2e-16	3.73
Bus	5.87971	0.30167	19.491	<2e-16	11.51
Truck	5.8866	0.62996	9.344	<2e-16	11.52

- Residual standard error: 1.907 on 139 degrees of freedom
- Multiple R-squared: 0.9307, Adjusted R-squared: 0.9288
- F-statistic: 467 on 4 and 139 DF, p-value: < 2.2e-16

This model again has high F-value and low p-value suggesting a strong relationship between the dependent and independent variables of regression. This model can successfully explain variation in saturation flow time up to 92%. The intercept of 0.277 signifies that during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.73 motorcycles, whereas 11.51 motorcycles and 11.52 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.519 seconds and saturation flow is 6,923 motorcycles per hour per lane.

Right turning vehicle at Thapathali intersection

The right turning vehicle volume for Thapathali intersection is taken for Tripureshwor-Kupondole approach and Maitighar-Tripureshwor approach. The result is summarized in Table 4-13:

Table 4-13: Calibration of right turning vehicle at Thapathali intersection

	Estimate	Std. Error	t-value	Pr(>|t|)	MEU value
(Intercept)	0.57534	0.42395	1.357	0.177	
Bike	0.54306	0.02539	21.385	<2e-16	1
Car	1.72134	0.11496	14.973	<2e-16	3.17
Bus	5.62927	0.29995	18.767	<2e-16	10.36
Truck	4.32737	0.62199	6.957	1.25e-10	7.97

- Residual standard error: 1.883 on 139 degrees of freedom
- Multiple R-squared: 0.9294, Adjusted R-squared: 0.9273
- F-statistic: 457.2 on 4 and 139 DF, p-value: < 2.2e-16

F-value is higher than 1 and p-value is lesser than 0.05, which shows significance of relationship in the regression equation. This model again explains variation in saturation flow time up to 92% based upon the numbers of flow of classified volume of vehicles in that time period. The intercept of 0.543 signifies that during many cycles the time required to clear of vehicles at saturation flow is higher than a single long cycle of saturation flow, ignoring initial head loss. A single car is equivalent to 3.17 motorcycles for right turning vehicles in Thapathali intersection, whereas 10.36 motorcycles and 7.97 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.734 seconds and saturation flow is 4,902 motorcycle per hour per lane.

Right turning vehicle at Kalimati intersection

The major traffic data for Kalimati intersection comprises of Balkhu-Teku approach. Minor volumes of Kalanki-Balkhu approach have been included for calibration of coefficients and MEU values. The result is shown in Table 4-14.

Table 4-14: Calibration of right turning vehicle at Kalimati intersection

	Estimate	Std. Error	t value	Pr (>|t|)	MEU value
(Intercept)	0.12171	0.4161	0.293	0.771	
Bike	0.55973	0.01919	29.168	<2e-16	1
Car	1.88877	0.10321	18.301	<2e-16	3.37
Bus	5.70233	0.25777	22.122	<2e-16	10.18
Truck	5.88789	0.26298	22.389	<2e-16	10.51

- Residual standard error: 1.277 on 100 degrees of freedom
- Multiple R-squared: 0.9732, Adjusted R-squared: 0.9721
- F-statistic: 908.2 on 4 and 100 DF, p-value: < 2.2e-16

This model successfully explains the variation in time required to clear right turning vehicles from Kalimati intersection with reliability of over 97%. The intercept of 0.121 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.37 motorcycles, whereas 10.18 motorcycles and 10.51 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.565 seconds and saturation flow is 6,374 motorcycles per hour per lane.

Right turning vehicle at Koteshwor intersection

Right turning traffic volume of Tinkune-Balkumari approach and Balkumari-Jadibuti approach have been utilized for the calibration of coefficients and MEU values. The result of calibration is shown in Table 4-15.

Table 4-15: Calibration of right turning vehicle at Koteshwor intersection

	Estimate	Std. Error	t value	Pr (>|t|)	MEU value
(Intercept)	0.11807	0.49373	0.239	0.812	
Bike	0.54618	0.02363	23.115	<2e-16	1
Car	2.00921	0.1117	17.988	<2e-16	3.67
Bus	5.5413	0.28263	19.606	<2e-16	10.14
Truck	5.76699	0.28937	19.929	<2e-16	10.56

- Residual standard error: 1.285 on 96 degrees of freedom
- Multiple R-squared: 0.9432, Adjusted R-squared: 0.9409
- F-statistic: 398.9 on 4 and 96 DF, p-value: < 2.2e-16

This model successfully explains the variation in time required to clear right turning vehicles from Koteshwor intersection with reliability of over 94% during saturation flow. The intercept of 0.118 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.67 motorcycles, whereas 10.14 motorcycles and 10.56 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.550 seconds and saturation flow is 6,539 motorcycles per hour per lane.

Right turning vehicle at Narayan Gopal intersection

Narayan Gopal intersection lies on ring road of Kathmandu valley. All four approaches of right turning traffic at this intersection was used for calibration of coefficients and MEU values. The result is summarized in Table 4-16:

Table 4-16: Calibration of right turning vehicle at Narayan Gopal intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	0.6089	0.4042	1.506	0.135	
Bike	0.5379	0.023	23.384	<2e-16	1
Car	1.8851	0.0972	19.394	<2e-16	3.50
Bus	5.9742	0.2168	27.552	<2e-16	11.11
Truck	6.5322	0.2278	28.675	<2e-16	12.14

- Residual standard error: 1.216 on 113 degrees of freedom
- Multiple R-squared: 0.9677, Adjusted R-squared: 0.9666
- F-statistic: 847 on 4 and 113 DF, p-value: < 2.2e-16

F-value is higher than 1 and p-value is lesser than 0.05, which shows significance of relationship in the regression equation. This model successfully estimates variation in saturation flow time up to 92% based upon the numbers of flow of classified volume of vehicles in that time period. The intercept of 0.6089 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.5 motorcycles, whereas 11.11 motorcycles and 12.14 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.556 seconds and saturation flow is 6,475 motorcycles per hour per lane.

Right turning vehicle at Chabahil intersection

The right turning traffic volume of Gaushala-Chuchepati approach and Chuchepati-Dhumbarahi approach. The result of regression has been summarized in Table 4-17.

Table 4-17: Calibration of right turning vehicle at Chabahil intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	-0.1816	0.5181	-0.35	0.727	
Bike	0.6139	0.0296	20.74	<2e-16	1
Car	1.9181	0.1221	15.71	<2e-16	3.12
Bus	6.0583	0.2661	22.77	<2e-16	9.87
Truck	6.2008	0.2617	23.69	<2e-16	10.1

- Residual standard error: 1.351 on 105 degrees of freedom
- Multiple R-squared: 0.9489, Adjusted R-squared: 0.947
- F-statistic: 487.6 on 4 and 105 DF, p-value: < 2.2e-16

This model can predict the time required to pass various classes of vehicles in right turning direction of traffic stream in Chabahil intersection with probability greater than 94%. The intercept of -0.181 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.12 motorcycles, whereas 9.81 motorcycles and 10.1 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.581 seconds and saturation flow is 6,191 motorcycle per hour per lane.

Right turning vehicle at Gaushala intersection

Major data for calibration of right turning vehicle at Gaushala intersection was of ring road approach. All other approaches were also involved in volume calculation, the result of which has been summarized in Table 4-18.

Table 4-18: Calibration of right turning vehicle at Gaushala intersection

	Estimate	Std. Error	t value	Pr(>|t|)	MEU value
(Intercept)	-0.73835	0.4789	-1.542	0.126	
Bike	0.6624	0.02736	24.211	<2e-16	1
Car	2.05098	0.12482	16.432	<2e-16	3.09
Bus	5.75701	0.27048	21.285	<2e-16	8.69
Truck	6.42109	0.27436	23.404	<2e-16	9.69

- Residual standard error: 1.304 on 95 degrees of freedom
- Multiple R-squared: 0.9543, Adjusted R-squared: 0.9523
- F-statistic: 495.4 on 4 and 95 DF, p-value: < 2.2e-16

This model can predict the variation in time required to pass various classes of vehicles in right turning direction of traffic stream in Gaushala intersection with reliability more than 94%. The intercept of -0.738 signifies that during many cycles the time required to clear of vehicles at saturation flow is lower than a single long cycle of saturation flow ignoring initial head loss. A single car is equivalent to 3.09 motorcycles, whereas 8.69 motorcycles and 9.69 motorcycles are equivalent to a single bus and single truck respectively. The average time headway for motorcycle is 0.634 seconds and saturation flow is 5671 motorcycle per hour per lane.

Calibration and validation of aggregated model for through traffic

Data for through traffic was compiled in a single sheet. The whole data was split randomly into 80% for calibration purpose and 20% for validation purpose. 10 folds cross validation method was employed to generate root mean square errors and R-squared errors for calibration purpose. Average of the 10 folds calibration purpose used yielded the following result:

$$Time = 1.643 + 0.432 * (volume\ of\ bike)$$
$$+1.355 * (volume\ of\ car)$$
$$+4.151 * (volume\ of\ bus)$$
$$+5.906 * (volume\ of\ truck)$$

Root Mean Square Error (RMSE)= 2.439 on 747 degrees of freedom

R-squared = 0.894, Adjusted R-squared 0.893

This model was used for validation purpose against 20% of the data reserved for validation purpose. The result of validation for aggregated through traffic model are as:

Root Mean Square Error: 2.435

R-squared: 0.893

Mean Average Error: 1.940

Calibration and validation of aggregated model for turning traffic

Similar approach was adopted as though traffic for right turning traffic. The whole data was compiled in as single sheet and split randomly into 80% for calibration purpose and 20% for validation purpose. 10 folds cross validation method was employed to generate root mean square errors and R-squared errors for calibration purpose. Average of the 10 folds calibration purpose used yielded the following result:

$$Time = 0.610 + 0.534 * (volume\ of\ bike)$$
$$+1.852 * (volume\ of\ car)$$
$$+5.744 * (volume\ of\ bus)$$
$$+6.325 * (volume\ of\ truck)$$

Root Mean Square Error (RMSE)= 1.619 on 746 degrees of freedom

R-squared = 0.941, Adjusted R-squared 0.94

This model was used for validation purpose against 20% of the data reserved for validation purpose. The result of validation for aggregated through traffic model are as:

Root Mean Square Error: 1.668

R-squared: 0.951

Mean Average Error: 1.226

The summarized form of Motorcycle Equivalent Unit of various intersection for through and right turning traffic is tabulated in Table 4-19.

Table 4-19: Aggregated model of through and right turning traffic

Vehicle group	Coefficients of through traffic	MEU through traffic	Coefficients of turning traffic	MEU right turning traffic
Bike	0.432	1	0.534	1
Car	1.355	3.13	1.852	3.47
Bus	4.151	9.60	5.744	10.76
Truck	5.906	13.67	6.325	11.84

4.3 Saturation rate of flow

The maximum number of vehicles that can pass through a given point is normally expressed in the units of number of vehicles per lane per hour. For the calculation of saturation rate of flow, we need to calculate headway for the vehicles. Since, lane discipline is not maintained, the headway calculated is pseudo headway. This time headway is calculated as if the total stream is converted into motorcycle units as per MCU. The formulae involved is

$$H = \frac{T}{\sum MCU_i * N_i}$$

This relation was used to calculate headway for through and right turning values of the total observation collected on spreadsheet. The compiled data sheet for through traffic and right turning traffic were used to convert classified group of vehicles to motorcycle equivalent. The result was then averaged over for the total observation. The time headway for through traffic if only motorcycle would exist equals to 0.47 seconds and the same for right turning traffic equals to 0.56 seconds.

The saturation flow in this research is the number of motorcycles that can pass through a given point per lane per hour. The time headway calculated from Thus, utilizing the given formula below for saturation flow of traffic in through and right turning traffic,

$$S = \frac{3600}{H}$$

The saturation flow for through traffic is 7,625 motorcycle per hour per lane and the saturation flow for right turning traffic is 6,492 motorcycle per hour per lane.

4.4 Effect of motorcycle proportion in headway

Since one of objectives was to study the effect of motorcycle proportion on headway, the aggregated sample for through traffic of eight intersections was used to study the effect of motorcycle proportion on headway of traffic stream. Headway of traffic stream was taken as dependent variable and proportion of two-wheeler as independent variable. The result of regression is shown in Table 4-20.

Table 4-20: Calibration of headway for through traffic

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	2.09446	0.05127	40.85	<2e-16
Proportion	-1.59922	0.06695	-23.89	<2e-16

- Residual standard error: 0.1665 on 937 degrees of freedom
- Multiple R-squared: 0.3785, Adjusted R-squared: 0.3778
- F-statistic: 570.6 on 1 and 937 DF, p-value: < 2.2e-16

With F-statistic greater than 1 and p-value very small, the inverse relation of headway and two-wheeler proportion can be easily deducted. However, statistically (R-value less than 0.5) using proportion of two-wheeler only cannot predict the headway of traffic stream. This can be attributed to the presence of other vehicle classes and their interaction with each other and two-wheeler.

Similarly, for turning vehicles, the result of regression is shown in Table 4-21

Table 4-21: Calibration of headway for right turning traffic

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	2.87834	0.05201	55.34	<2e-16
Proportion	-2.33886	0.06626	-35.30	<2e-16

- Residual standard error: 0.1864 on 936 degrees of freedom
- Multiple R-squared: 0.571, Adjusted R-squared: 0.5706
- F-statistic: 1246 on 1 and 937 DF, p-value: < 2.2e-16

This model also only explains that the proportion of two*wheeler in an intersection can estimate the variation of average headway up to 57%. This model also has higher F-value and lesser P-value. Though statistically we may need adjusted R-squared value close to 1, lower p-value represents the existence of significant relationship. Since, the specific objective of this study was to study effect on headway because of motorcycle, the inverse relation i.e. increases in proportion of motorcycles leads to decrease in headway of traffic stream is inferred.

4.5 Effect of motorcycle proportion in saturation flow

The main objective of this study was to study the effect of motorcycle on saturation flow in an intersection. The effect of motorcycle proportion on saturation flow study was also based on simple linear regression model with bike proportion in traffic as independent variable. The result of two-wheeler proportion on saturation flow is shown in Table 4-22.

Table 4-22: Calibration of saturation flow for through traffic

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	-1390.1	242.1	-5.742	1.26E-08
Prop	7517	316.1	23.778	<2e-16

- Residual standard error: 786.3 on 937 degrees of freedom
- Multiple R-squared: 0.3763, Adjusted R-squared: 0.3757
- F-statistic: 565.4 on 1 and 937 DF, p-value: < 2.2e-16

Statistically, proportion of two-wheeler is directly proportional to the saturation flow of vehicles, but estimation of saturation flow is not significantly predicted only using proportion of two-wheeler as independent variable.

Similarly, the effect of motorcycle proportion on saturation flow was observed from data taken for calculation of relation between average headway and bike proportion in right turning traffic. The result of regression is presented in Table 4-23.

Table 4-23: Calibration of saturation flow for right turning traffic

	Estimate	Std. Error	t-value	Pr (>|t|)
(Intercept)	-2269	179.2	-12.66	<2e-16
Prop	7598	228.4	33.28	<2e-16

- Residual standard error: 642.3 on 936 degrees of freedom
- Multiple R-squared: 0.5419, Adjusted R-squared: 0.5414
- F-statistic: 1107 on 1 and 936 DF, p-value: < 2.2e-16

This statistical calculation again shows the result that there is significant direct relationship between proportion of motorcycle in right turning traffic and saturation flow as F-value is significantly greater than 1 and p-value less than 0.01. However, proportion of bike can only account for 54% of variation in saturation flow.

4.6 Comparison with previous study

Various studies have already been made for the calculation of PCU and MCU values. For the sake of simplicity for comparison, the PCU values of the respective research has been converted into motorcycle equivalent unit by simply dividing each value with the value provided for two-wheelers. The comparison for through traffic is tabulated in Table 4-24

For through traffic, the value of equivalence unit of car is greater than provided by NRS 2070 and *Subedi (2016)*, but less than proposed by *Shrestha (2016)* and *Shrestha (2014)*. The value for bus is however lower than provided by Shrestha (2013) but greater than other researchers and NRS 2070. The equivalent unit for truck is however found to be higher than any other researches and NRS 2070.

Table 4-24: Comparative study of equivalent units

Researches	MCU value			
	Two-wheeler	Car	Bus	Truck
This study (through)	1	3.13	9.60	13.67
This study (right turn)	1	3.47	10.76	11.84
Shrestha (2016)	1	5.14	12.81	-
Shrestha (2014)	1	4	8.76	10.6
Subedi (2016)	1	2.27	6.66	6.61
NRS 2070	1	2	6	6

Shrestha (2016) recommended saturation flow (Q=10380W-23310) of a lane as 13,020 motorcycle units per hour per lane. *Shrestha (2014)* proposed similar model with width as variable for saturation flow calculation (S=1107+398.22*W) amounts to 2500 veh/hr/lane which is passenger car unit which when converted to motorcycle unit by the value of two-wheeler in her research amounts to 10,000 motorcycles per hour per lane. This research study however proposes the saturation flow rate for through traffic at an intersection to be 7625 motorcycles per hour per lane. The saturation flow of right turning traffic is found to be 6,492 motorcycles per hour per lane. Shrestha (2016) has utilized area velocity method for the estimation of motorcycle equivalent units and utilized motorcycle following motorcycle to account for the headway time and taken only width as criteria for estimating saturation flow, which could probably have led to difference with his numbers Having extrapolated saturation flow for intersections, Shrestha (2013), has also linked saturation flow to width of lane only, which could have led in the discrepancy with this study. However, since this study shows that the higher the percentage of two wheelers in the traffic stream results in higher saturation flow, saturation flow value is similar to Shrestha (2016).

CHAPTER FIVE : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Eight intersection were selected for study the effect of two-wheeler on saturation flow and headway in traffic stream. The study found volumetric proportion of two-wheeler in every intersection and movement to consist of more than 50%. Video-graphic data was employed to perform temporal count of various classes of vehicles.

Firstly, the PCU values provided by NRS 2070 is not suitable for calculation of saturation flow of urban intersections. There is minor difference (0.4 in car, 1.5 in bus and 1.5 in truck) in equivalent unit values in through and right turning direction. This can be due to proportional decrease in the saturation flow of every group of vehicles. The values obtained are tabulated in Table 5-1.

Table 5-1: Motorcycle Equivalent Units of various class of vehicles

	Equivalent units	
Vehicle group	Through	Right-turn
Bike	1	1
Car	3.03	3.44
Bus	9.21	10.77
Truck	13.42	11.92

Secondly, average headway for through traffic is 0.47 second and for right turning traffic is 0.56 second. The saturation flow rate for through vehicles is 7,625 motorcycles per hour per lane and right turning vehicles is 6,492. The relation between average headway and the proportion of two-wheelers is inverse whereas saturation flow increases with increase of motorcycle proportion in traffic stream.

Finally, this study found that the increase in proportion of two-wheeler in traffic stream of intersection decreases time headway and subsequently increases saturation flow of traffic.

5.2 Recommendations

Video-graphic data showed the penetration effect of two-wheeler in the traffic stream during manually signalized red phase of traffic movement. The maneuverability of two wheelers and both side overtaking movement results dominant volume in the early phases of traffic flow. Some of the lanes studied in through traffic were of double lanes which were converted to single lane to ease in calculation and comparison. The calculated saturation flow value and headway are thus a result of combination. The absence of proper lane segregation resulted in spillback and spillover effect. Right turning vehicle (red phase) in queue would alter the flow of through vehicles (green phase). Thus, some of the recommendations for further work are:

- Study of saturation flow at places with lane discipline
- Study of saturation flow in channelized intersection
- Effect of spillback and spillover effect

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APPENDIX A: SAMPLE CODE FOR VALIDATION

```
sink("ThroughValidation.txt")                                   #opens file
data<-read.csv("through.csv", header=TRUE)                      #input data (through vehicles)

data_ctrl<-trainControl(method = "cv",number=10)                #Cross validation
mc<-train(time~bike+car+bus+truck,
      data=data,
      trControl=data_ctrl,
      method="lm",
      na.action = na.pass)                                      #linear regression
split<-createDataPartition(y=data$time,p=0.8,list=FALSE)        #data split, 80% for calibration

cal<- data[split,]                                              #Calibration Data
val<- data[-split,]                                             #Validation Data

lmFit<- train(time~bike+carr+bus+truck,
        data=cal, trControl=data_ctrl,
        method="lm")                                            #Calibration LOOCV
predictedValues<-predict(lmFit, val)                            # Validations
modelvalues<-data.frame(obs=val$time, pred=predictedValues)     #model values
residualsCal<-resid(model)                                      #writes residuals
modelvalues                                                     #writes values
summary(lmFit)                                                  #gives summary of regression
sink()                                                          #Close text file
```