Development of Saturation Flow and Delay Model at Signalised Intersection of Kathmandu

Sambriddhi Shrestha[1], Anil Marsini[2]

Department of Civil Engineering, Central Campus, Pulchowk, IOE, TU, Nepal

Corresponding Email: shrestha.sambriddhi@gmail.com

Abstract: Intersection is the most crucial element of road network as it affects the performance and productivity of the whole network significantly. The intersection performance is usually measured via delay and saturation flow rate. This research work determines an equivalency factor (PCU values) for different categories of vehicles and a basic saturation flow model along with a delay model in the context of non-lane based heterogeneous traffic condition of Kathmandu. The analysis is based on video graphic and GPS data collected at three selected intersections of the city. The outcome of the developed models shows very good correlation with the observed data. The developed models are recommended for the determination of saturation flow and delay at other signalized intersections of Kathmandu valley and these can be further used in the planning and design of intersection and road network in a whole.

Keywords: Capacity; Saturation flow; PCU; Delay; Heterogeneous traffic

1. Introduction

As the number of vehicles is increasing, the problem of congestion is also increasing simultaneously. Congestion at the intersection is the most crucial element of road network as it affects the performance and productivity of the whole network. Intersection is the location where vehicles moving in different direction want to occupy same space at the same time. In addition, the pedestrians also seek same space for crossing.

In Nepal, to control the traffic at Kathmandu, fixed time traffic signals and traffic police controlled intersections are being used. The important parameters in the planning, design and control of a signalized intersection are saturation flows, lost times, passenger car units (PCU) and delay. These factors have been traditionally measured, in most western countries, based on the research carried on roads where traffic is typically car-dominated with vehicles moving in clearly defined lanes. However, the traffic movement in Kathmandu is more complex due to the heterogeneous characteristics of the traffic stream using the same right of way with high percentage of motorcycle. Another striking feature of the road traffic operating condition in Kathmandu is that, most of the times lane discipline is not followed. Hence it is unwise to use the standard western relationships for predicting the values of saturation flows, lost time, PCU factors and delay. For correct signal design these parameters should be estimated based on the local prevailing traffic conditions and hence requires a different approach to analysis.

This research aims to study the present procedure to analyze the capacity of intersection and suggest a modification for heterogeneous traffic condition.

2. Site Selection

One of the main problems seen in Kathmandu valley is traffic jam. The study area selected for the analysis is Kathmandu. Three signalized intersections: Koteshwor, Tinkune and Jadibuti were selected for the study. All intersections have pre-timed signal control system.

3. Data Collection

The data necessary for this study are described below:

a) Road Geometry

   It includes number and width of the lane, parking condition, length of storage bay if any, etc.

b) Traffic data

   It includes vehicle count during the saturation flow period for the determination of saturation flow and speed of the vehicle every second for the determination of delay.

c) Signal data

   It includes the type of signal, cycle length and the green time for each lane.

The width of each lane under consideration was measured using an electronic tape. The cycle time and green time for each lane group was measured using stopwatch. Three days 24-hour traffic volume count of Manohara Bridge which is located near our site was collected to determine the peak hour. Then data were collected at the site during peak hour. It was decided to use a video recording technique for data collection by placing it at vantage point to cover the traffic flow over the entire approach. The data for traffic flow was recorded and later analyzed.

The data for development of delay model was collected using a GPS device which automatically records time, coordinate, direction and speed of the vehicle every 1 second. Motorcycle and car were used for the data collection. The data were collected from Tinkune to Jadibuti and back from Jadibuti to Tinkune which consists of three signalized intersections. Seven rounds were made along the route for each vehicle in both directions. Out of which 4 rounds were made during the evening peak and 3 rounds during morning peak.

4. Data Retrieval

The recorded video was replayed in the computer to extract the desired information. Saturation flow time and classified vehicle counts were collected from the video recorded for the calculation of PCU and saturation flow.

Observation point was selected by playing video recordings. The stop line was considered the observation point. Start of the green was noted down from video camera timer. Initial 10 seconds from the start of green are left to take into account start up loss time. Saturation flow ends when the rear axle of the last vehicle from a queue crosses the stop line. 10 seconds after the start of green time the classified vehicles were counted until the last vehicle in the queue crossed the observation point. It is not possible to count all classified vehicle count at a time for all movements. Therefore, video was replayed number of times and every time vehicle count of one or two category was done. The above procedure was repeated for each cycle of recorded period.

GPS device records the speed, time, coordinate and direction of the vehicle every second. Using these data distance travelled and acceleration of the vehicle every second were calculated in spreadsheet.

5. Data Analysis

As the traffic flow of Kathmandu is heterogeneous, so saturation flow in vehicle per hour is not used. Instead saturation flow is calculated in PCU per hour.

5.1. Estimation of Passenger Car Unit

The traffic operation at signalized intersection would be very much easier and simplified if all vehicles in the traffic stream were of an identical size and travelled straight ahead only. In practice, however, the operations are complicated because the traffic stream normally consists of an inseparable mixture of different types of vehicles performing different maneuvers at the traffic intersection. The non-uniformity in the static and dynamic characteristics of the vehicles is normally taken into account by converting all vehicles in terms of common unit. The most accepted unit is passenger car unit (PCU). The foremost drawback of PCU concept is the ambiguity in its definition, which makes everyone to determine PCU values in a different manner.

In the present study, multiple regression analysis was used for the determination of PCU values. The vehicles were divided into 6 different categories: Car, Bus, Truck, Microbus, Two-Wheelers and Tempos. Non-motorized vehicles were almost absent in the study area so they are not considered in the study.

The general form of regression equation is as given:

$$T = a_o + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6$$

Where,

T = saturated green time (sec),

a_o = y-intercept,

$a_1, a_2, a_3, a_4, a_5, a_6$= coefficient for Car, Truck, Bus, Two-Wheeler, Microbus and Tempo respectively

$x_1, x_2, x_3, x_4, x_5, x_6$ = number of vehicles of each category in time

Then, Passenger Car Unit of vehicle type i,

$$PCU_i = \frac{a_1}{a_i}$$

Where,

a_1= coefficient for car

a_i = coefficient for each category

The PCU values for some vehicles at some lane were found negative or too high or too low. It may be due to very low percentage of those vehicles. Such values were ignored and only those PCU with significant t-values were selected and average PCU values were calculated and compared with NRS values.

Average calculated PCU value

PCU	Car	Truck	Bus	Two-Wheeler	Microbus	Tempo
Estimated Value	1	2.65	2.19	0.25	1.67	1.3
NRS Value	1	3	3	0.5	1.5	NA

The truck represents all types of trucks including multi axel truck, heavy truck as well as tipper. As the volume of truck is very low in that area, all types of truck were considered in the same category. The bus also represents all types of bus including mini bus to large bus.

5.2 Estimation of Saturation Flow (PCU/hr)

Saturation flow is estimated in PCU/hr using average PCU for all the intersections. Conventional procedure is adopted to find out saturation flow value for each approach. First, the saturated green time (T sec) is divided by the number of different categories of vehicles that have been converted into passenger car unit to get the time headway. Inverse of headway gives the saturation flow.

Thus the saturation flow in PCU/hr is obtained as:

$$S = \frac{\left(\begin{matrix} PCU_C*x_1+PCU_T*x_2+PCU_B*x_3+ \\ PCU_{TW}*x_4+PCU_{MB}*x_5+PCU_{Tem}*x_6 \end{matrix}\right)*3600}{T}$$

6. Development of Saturation Flow Model

A study into the saturation flow of signalized intersections under non lane based traffic would require a large database from field over a range of traffic flow and geometric conditions (Turner et al 1993). Such a large database from the relevant situation is not available. In present study, field data have been collected at nine approaches. Using this data, multiple regression analysis has been made in order to estimate the saturation flow in passenger car unit per hour.

First of all, queue length at each intersection were observed to check if the effect of previous intersection is seen on the intersection and it was found that sufficient clearance distance is available between the queued vehicle and the adjacent intersection. This shows that the adjacent intersection doesn't affect the saturation flow.

The independent variables used are listed in table below. Selection of these variables was largely on the basis of ease of collection and the experience of earlier studies.

Independent Variables used for Saturation Flow

Independent Variable for Saturation Flow	
Variable	Variable Name Description
WIDTH	Width of study approach at stop line being surveyed
SIGSET	Length of signal green time for approach being surveyed
%RT	Percentage of right turning vehicle (Include all types of vehicle)
%HV	Percentage of Heavy Vehicles
% TW	Percentage of Two-wheelers
P	Parking

All these variables were regressed to find the saturation flow and some of the models are given below:

S.N	Model	R^2
1	S=1107+398.22 W	0.415
2	S = 525.88 W	0.956
3	S = 2579 + 318 W - 11.35 GT -	0.434
4	S = 497.6W+2.12 GT +405.8%RT	0.959
5	S= 456.2W+0.465GT+293%RT+1970%HV+558%TW	0.959
6	S=435W-0.66GT+353%RT+3145%HV+1029%TW-456P	0.961

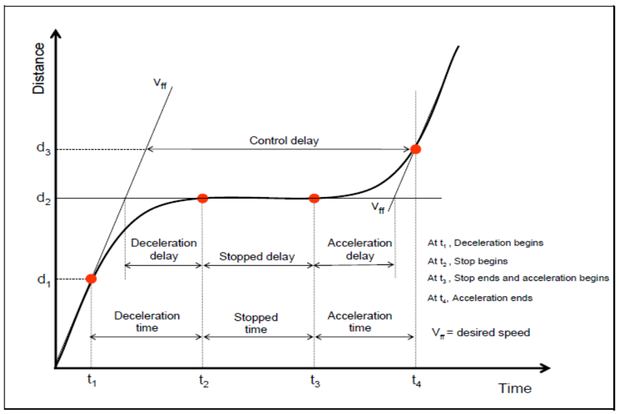
Statistical parameters of model 2, model 4, model 5 and model 6 are close to each other. Out of these models, model 2 is the simplest model and has the satisfactory value of R square. Hence, Model 2 is proposed in this study to estimate saturation flow for non-lane based traffic condition.

7. Delay Analysis

In this study, a relation between control delay and stopped delay was obtained.

Field measurement of delay was done at 3 intersections for 7 times in both the direction. GPS device and a motorcycle were used for data collection. GPS device records the location and speed of the vehicle every second. From the speed and time interval, distance travelled in every second was calculated in Microsoft Excel. Data was collected for 2 days during morning and evening peak hour.

Finally data of each intersection were separated and used for the preparation of Speed Vs Time, Acceleration Vs Time and Distance Vs Time graph of each intersection.



Distance vs time curve

The distance corresponding to the critical point T_1 is d_1, and distance corresponding to timeT_4isd_4. The slope of the curve before the vehicle starts decelerating represents the desire speed.

Using the graphs, point where vehicle starts to decelerate (T_1), stops (T_2), starts (T_3), stops to accelerate (T_4), measured length at which deceleration starts (d_1), measured length at which accelerations ends (d_4) and the projected running speed of the trajectory (S_r) were determined.

Using these data, controlled delay and stopped delay were determined using the equations:

$$D_s = T_3 - T_2$$

$$D_c = (T_4 - T_1) - (d_4 - d_1)/S_r$$

Distance/Speed /Acceleration Vs time graph at each location were also constructed and used for determination of control and stopped delay. Using those graphsT_1,T_2, T_3, T_4, L_1, L_4 and S_r were identified for each GPS run. T_2andT_3 can be easily identified by determining the time where the vehicle stops and starts respectively. T_1can be identified by determining time where the vehicle starts decelerating and T_4 where the vehicle stops accelerating. $d_1$andd_4 are the distance travelled corresponding to T_1andT_4 respectively.

The running speed (S_r) was calculated for each GPS run as the average mid-block speed at which the vehicle was not decelerating or stopped near the downstream signal and not accelerating near the upstream signal. This was calculated by determining the slope of the Distance Vs Time Curve before the vehicle started to decelerate and after the vehicle stopped to accelerate.

Once all these parameters were determined, D_c and D_s were determined in the Microsoft excel sheet as shown in **Error! Reference source not found.**, using the equation:

$$\mathbf{D_s = T_3 - T_2}$$

$$\mathbf{D_c = (T_4 - T_1) - \frac{d_4 - d_1}{S_r}}$$

Where,

T_1= GPS time where the vehicle starts to decelerate

T_2=GPS time where the vehicle comes to complete halt,

T_3=GPS time where the vehicle halt ends,

T_4=GPS time where the vehicle ends accelerating,

d_1=Measured length at which deceleration starts,

d_4=Measured length at which acceleration end and

S_r=Projected running speed of the trajectory.

D_s= Stopped delay in seconds

D_c=Control delay in seconds,

Finally a regression model had been developed for control delay using stopped delay as independent variable by considering each intersection delay parameters. By considering both the directions data a common equation is developed, as most of the intersections are having similar characteristics.

S.N	Model	Adjusted R^2
1	$D_c = 16.1 + 0.979\ D_s$	0.95
2	$D_c = 1.271\ D_s$	0.93

Two models were developed, first by considering constant as non-zero and next by considering constant as zero. The adjusted R square values of both the equations were compared. The adjusted R square value of the equation where constant is a non-zero has the higher value, so this equation is more efficient.

Developed model 1 was tested using the GPS data collected at the same location using car. Using graph from appendix T_1, T_2, T_3, T_4, L_1, L_4 and S_r were identified for each GPS run. Control delay calculated using the model showed good correlation with the field data. R square was found to be 0.983. So, it is recommended that this model can be used for car also.

8. Summary

Accurate saturation flow values are a fundamental building block in the management of efficient urban traffic signal control and intersection design. In this chapter, initially A ranges of site-specific PCU values were obtained using synchronous multiple linear regression. The saturation flow for each survey approach was calculated using the average PCU values and multiple linear regression techniques were then used to derive predictive saturation flow models. The saturation flow values for full approach were regressed against several intersection characteristics. The resulting models and statistical performance indicators were reported than. For delay model, motorcycle and car were used for data collection. The data collected using motorcycle was used to develop a relationship between control and stop delay whereas the data collected using car was used to validate the same model.

9. Conclusion

This study proposes a new PCU values for different classes of vehicles for the heterogeneous traffic condition of Kathmandu.

From the present work following conclusion were made:

- The PCU value suggested for the heterogeneous traffic condition of Kathmandu is,

  Car=1
  Truck=2.65
  Bus=2.19
  Two-wheeler=0.25
  Microbus=1.67
  Tempo=1.3
- The regression model developed for saturation flow rate is mainly based on approach width,

  S = 525.88 W
- Regression model developed to estimate saturation flow showed good correlation with field value.

  The relationship developed between stopped delay and control delay from our study is

  $$D_c = 16.1 + 0.979\, D_s$$

  The relationship developed using motorbike data was validated using car data.

10. Recommendation

1. The regression model developed for saturation flow is based on traffic data collected from 3 signalized intersections of Kathmandu. Further study needs to be done considering more intersections.
2. Vehicles were classified into only six different categories. Multi axel trucks, heavy truck and tippers; mini bus and large bus were all considered in a single group.
3. Saturation flow depends on various factors. In present study, effect of grade, pedestrian flow, non-motorized vehicles etc. were not considered. All these factors needs to studied and develop new model taking into account maximum possible variables.
4. The saturation flow model is developed has considered right and through moving vehicles, effect of left turning vehicles on saturation flow must be checked.
5. Recommended relationship between stopped delay and control delay has been developed using motorcycle only. Further study needs to be done using other vehicles also.
6. The variation of saturation flow with time and day was not considered in the present study. Further study needs to be done.

References

Transport Research Board. (2000). *Highway Capacity Manual.* Washington D.C.: Transport Research Board.

Government of Nepal, Ministry of Work and Transport. (2045). *Nepal Road Standards*. Department of Roads.

Abrahim Morjan. (2012).*Application of Global Positioning System to Travel Time and Delay Measurement*. Delaware Center for Transportation, University of Delaware.

Allam Sivakanth. (2008). *Study of Typical Parameters at Signalized Intersections*. M. Tech. Thesis, Department of Civil Engineering, Indian Institute of Technology, Bombay.

Gopal R.Patil.(2002).*Capacity Analysis of Signalized Intersection in Developing Countries*. M. Tech, Thesis, Department of Civil Engineering, Indian Institute of Technology, Bombay.

J Turner and G Harahap. (1993).*Simplified Saturation Flow Data Collection Methods*. Journal, Oversead Centre Transport Research Laboratory, Crowthorne, UK.

Ko, J., Hunter, M., and Guensler, R.(2007).*Measuring Control Delay Using Second-by-Second GPS Speed Data*. Institute of Technology, Georgia.

Md. Hadiuzzaman.(2008). *Development of Saturation Flow and Delay Models for Signalised Intersection in Dhaka City*. M.Sc. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology.

Ragab M. Mousa, M.ASCE. *Analysis and Modelling of Measured Delays at Isolated Signalized Intersections*. Journal of Transportation Engineering, Vol.128, No. 4

Wassim Kebab and Michael Dixon (2006). *Field Measurement of Delay at Signalized Intersections*. Report, National Institute for Advanced Transportation Technology University of Idaho.