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The Effect of Geometric Factors on Saturation Flow at Selected Intersections of Kathmandu

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***Abstract*: The main objective of intersection design is to facilitate the convenience, comfort and safety of people traversing the intersection by enhancing the efficient movement of road users. The intersections on urban roads in Nepal generally cater heterogeneous motorized traffic, along with slow-moving traffic including pedestrians. It is therefore necessary to consider saturation flow for mixed traffic conditions to evaluate the overall operation of signalized intersections. A This paper presents the results of the study on analyses of saturation flow rate conducted at signalized intersections with mixed traffic conditions in Kathmandu, Nepal. Studies were carried out at 19 signalized junctions in Kathmandu with varying geometric factors such as width of road (w), gradient of road (g), and turning radius (r) for right turning vehicles. Saturation flow rate at first was computed as per Highway Capacity Manual (HCM: 2000). Then geometric factors, which affect the saturation flow, have been considered in this study and accordingly a new model has been proposed for determining saturation flow. It has been shown that by the introduction of the suggested adjustment factors in this paper, the saturation flow rate can give better picture of the field conditions, especially under heterogeneous traffic conditions of an urban area**

***Keywords*: Saturation Flow, Signalized Intersection, Heterogeneous Traffic, Adjustment Factor.**

1. Introduction

The growth of traffic in the road network of cities in developing countries, like Nepal, is a serious concern from the traffic engineer's point of view. In developing countries like Nepal, road traffic in general and urban roads traffic is highly heterogeneous, comprising vehicles of widely varying static and dynamic characteristics. Further, the vehicles have the same road space without separate lanes. Knowledge of basic traffic flow characteristics like traffic volume under such heterogeneous conditions is fundamental, since traffic volume is the basic input variable in planning, designing and operation of roadway systems.

The saturation flow required to calculate the capacity of a signalized intersection can be obtained in two ways. First approach involves conducting field studies to measure saturation flows at intersections of interest. In this approach, capacity influencing factors are empirically included, and the measured saturation flows represent the capacity of the intersections under the existing conditions.

The second approach to the problem involves the use of "base saturation flow values," such as theoretical maximum values. These base values can be adjusted to account for the physical and operating conditions of the intersections, approaches being analyzed and used in intersection capacity studies. The assumption implicit in the use of base flow rates in capacity studies is that quantifiable relationships exist between saturation flows and the physical and operating characteristics of signalized intersections.

Signalized intersections use a common form of traffic control to address roadway operations. Signalized intersections allow road users to access new streets and change in the direction of travel. Intersections should be able to serve their varying traffic demands, provide minimum delay in passage, and maximum safety to all types of users especially pedestrians. One generally evaluates the functioning of a typical signalized intersection in two parameters: 1) capacity, that is, volume to capacity (v/c) ratio, and 2) the level of service (LOS), with its delay and queue ranges. These parameters are functions of traffic volume characteristics, signal characteristics and geometry of the intersection. One evaluates the capacity on the concept of saturation flow, whereas, LOS is measured based on the delay that a user experiences, while crossing an intersection.

2. Review of the literature

Several studies have been carried out on HCM [1] signalized intersection model, its applicability, and its modifications. This section addresses some of traffic model proposed so far, for modeling heterogeneous traffic movement at signalized intersections. Some research works related to saturation flow rate for signalized intersections have been presented in this section.

A. Highway capacity manual

The highway capacity manual (HCM) is published by Transportation Research Board (TRB) of the National Academies of Science in the United States. It offers standards, tips, and computational tactics for calculating the capacity and fine of carrier of various motor way centers, such as freeways, highways, arterial roads, roundabout, signalized and un-signalized intersections, rural highways, The effect of mass transit, pedestrians, and bicycles at the overall performance of these systems. It has also serving as a base for numerous

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Nations, specific capacity manuals.

The main hypothesis behind the project of developing Indonesia Highway capacity manual (IHCM), is Indonesian traffic characteristics are basically different from those of developed countries. Existing capacity manuals from such countries therefore cannot be successfully implemented in Indonesia. The main aim of research behind the production of IHCM manual has been to explore and model Indonesian driver behavior and fundamental road traffic characteristics by means of extensive field data collection and analysis.

The Central Road Research Institute(CRRI), India is one of the research institute under the umbrella organization Council of Scientific and Industrial Research(CSIR), has undertaken a national study to develop the Indian Highway Capacity Manual(Indo-HCM)[2].

B. Study on Saturation Flow Rate of Signalized Intersections

Sambridhi (Shrestha & Marsani, 2014), conducted a study in Nepal formulating regression model to estimate saturation flow rate which shows good correlation with field values. Study carried out by Alam (H.O. & zaha, 2010) at Makkah, Saudi Arabia, has shown that saturation flow rate and capacity adjustment factor for signalized intersections varied from HCM recommendations. However, the outputs can form the basis formulating a HCM for the country and therefore estimated parameters is also useful for signal design and traffic system performance in Saudi Arabia. Study conducted by Shao (J. & Liu,2011) at china , on base saturation flow was found to be 1800 puc/hg and factor of width ,turning radius and gradient affects are studied and a model is developed based on that, which yield better realistic field conditions. B.G.and H.S (Savita and Jagdish, 2017) conducted a study in India, which shows that the geometric factor affects the saturation flow at signalized intersection and model was developed from the filed data. The adjustment factor has been given that is different from HCM adjustment factor that gives the better realistic picture of the field conditions especially under heterogeneous traffic conditions of an urban area. Study conducted by Shao and C (Liu and X) at Beijing revealed that for different signalized intersections, the queue discharge headway distribution is often not identical. IRC:SP41-1994 showed guidelines for design at grade intersections for rural and urban area, has defined saturation flow as S =525*W, puc/hg(s-saturation flow in pcu/hr , width of road in m) for roads having width above 5.5 m, and gives saturation flow rate based on radius of right turning vehicles. However, it does not specify anything about defining LoS for signalized intersections. Study was conducted by N and Velmurungen (chand & jain, 2016) in new- Delhi India developing saturation flow model at signalized intersection and estimate the saturation flow and methodology was developed to calculate PCU for mixed traffic. Another study [9]in japan has developed saturation regression model for shared left turn lane at signalized intersections. In this study numerical model is proposed to test the effect of lane blockage and significant influencing factors on saturation flow rate estimation in shared left turn lane .Study from India [10] shows that saturation flow is affected by geometric factor and head way method is not adopted to calculate saturation flow rate due to non-disciplined road and there is significant lateral movement among vehicles and this study has given the PCU and geometric adjustment factors from the field data.

3. Methodology

A. Site Selection

Three signalized intersections were chosen for the for present study (Gaushala, Maharajgang Chakrapath and Satdobato intersections). All are four legged intersection having heavier through traffic flow during peak hours and long queue is formed. The effect of lane width, approach gradient and right turning radius on saturation flow rates are analyzed using Multi-linear regression model. These study areas are accessible via public bus, tempo, micro, taxi and two wheelers etc.

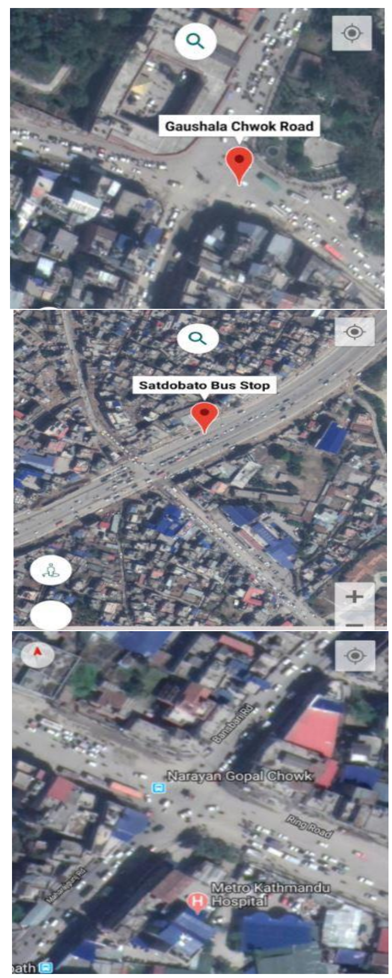

Fig. 1. Study Area

B. Data Collection

During the primary survey, data related to traffic and topography of the study area was collected. Traffic Data was collected during peak hour 9 am to 11 am and 3 pm to 5 pm for

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Table 1
Related geometric data at selected intersection

S. No.	Lane Group	Width (m)	Gradient (%)	Right Turning Radius (m)
1	Hatiban to Koteshwor Rt	7	0.5	27.3
2	Kalanki to Hatiban Rt	7	-0.5	29.8
3	Kalanki to keshwor Th	11	0.5	9999
4	Lagankhel to Hatiban Th	6	-0.5	9999
5	Koteshwor to Lagankhel Rt	4.5	0.5	19
6	Koteshwor to kalanki Th	11	0.5	9999
7	Hatiban to Lagankhel Th	6	0.5	9999
8	Gaushala to Mitrapark Rt	8	6	27
9	Mitrapark to old Baneshwor Th	6	-2	9999
10	Old Baneshwor to Mitrapark Th	5	2	9999
11	Mitrapark to Gyanshwor Rt	4	-2	32
12	Airport to Gyanshwor Th	5.5	6	9999
13	Gyanshwor to Airport Th	6.5	8	9999
14	Dhumbarahi to Basundhara Th	10	0.5	9999
15	Basundhara to Dhumbarahi Th	12	4	9999
16	Gangalal to Lainchaur Th	7	0.5	9999
17	Lainchaur to Gangalal Th	6	-0.5	9999
18	Dhumbarahi to Gangalal Rt	5	0.5	21
19	Gangalal to Basundhara Rt	3.5	-0.5	23

three days. The following necessary data are described below:

Traffic data: The traffic data was collected by videography method. Video camera was placed at vantage point to cover flow over the entire approach at required intersection. From the videography through flow and right turn flow data were collected along with the vehicle categorization in six different categories is shown in appendix.

- Bus
- Micro-bus
- Truck
- Two-wheeler
- Car
- Tempo

Road geometric data: It involves the lane width, approach gradient and right turning radius which are obtained from measurement tape, abney level, compass and videography.

Representation of the geometric data as lane width, approach gradient and right turning radius for selected intersection is shown in above figure and table 1 provide the clear information about the lane width, approach gradient and right turning radius.

Signal Data: This include the saturation time and green time which is shown in appendix.

C. Data Extraction

The recorded video was replayed in the computer to extract the required data. Saturation flow green time and classified vehicle counts were collected from the video recorded for the development of saturation flow, modeling and other information related other objective. Observation point was selected by playing video recordings. Start of green time will be noted 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 shall be counted until the last vehicles 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 cycles of recorded period. Vehicles are classified as:

1. Car
2. Light vehicles: micro bus, utility vehicles, four-wheel drive,
3. Three wheeler vehicle tempo
4. Heavy vehicle: multi axle, heavy truck, light truck
5. Two wheeler motorbike
6. Bus: standard bus, mini bus

D. Estimation of Saturation Flow (in PCU/hr)

The normally headway method based on time headway of passing vehicles cannot be used for non-lane based traffic condition, because, in non-lane based traffic flow, headways is hard to observe, as vehicles do not move in definite lanes. Traffic is analyzed based on total width of approach and hence, the option of vehicle counting is adopted saturation flow is considered autonomously for each observed saturation period and then averaged over observed cycles. Saturation flow was estimated in PCU/hr using the PCU values given by JICA survey report in 2012. Saturation green time (T sec) was 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 was obtained as:

$$S=(PCU_C*x_1+PCU_T*x_2+PCU_B*x_3+PCU_{TW}*x_4+PCU_{MB}*x_5+PCU_{TEM}*x_6)*3600/T$$

Where,

T= saturation green time (sec)

X_1, x_2, x_3, x_4, x_5, x_6=Number of Car, Truck, Bus, Two wheeler, Microbus and Tempo respectively

PCU_C, PCU_T, PCU_B, PCU_B, PCU_{TW}, PCU_{MB}, PCU_{TEM}=Passenger Car Unit of Car, Truck, Bus, Two Wheeler, Micro Bus and Tempo.

Table 2
Average calculated PCU Value

PCU	Car	Light truck	Mini bus	Two wheeler	Micro bus	Tempo
JAICA survey report 2012 of Kathmandu	1	1.5	3	0.3	1.5	1
NRS 2070	1	1.5	3	0.5	1.5	NA
SMRIDHI REPOR to saturation flow	1	2.65	2.19	0.25	1.67	1.3

Table 3
Saturation Flow Values at Selected Intersections

S.No.	Lane group	Saturation Flow (PCU/ hr.)	Width (m)	Gradient (%)	Right Turning Radius (m)
1	Hatiban to Koteshwor Rt	3544	7	0.5	27.3
2	Kalanki to Hatiban Rt	3546	7	-0.5	29.8
3	Kalanki to Koteshwor Th	5696	11	0.5	9999
4	Lagankhel to Hatiban Th	3468	6	-0.5	9999
5	Koteshwor to Lagankhel Rt	2144	4.5	0.5	19
6	Koteshwor to Kalanki Th	5645	11	0.5	9999
7	Hatiban to Lagankhel Th	3485	6	0.5	9999
8	Gaushala to Mitrapark Rt	4060	8	6	27
9	Mitrapark to old Baneshwor Th	3255	6	-2	9999
10	Old Baneshwor to Mitrapark Th	2698	5	2	9999
11	Mitrapark to Gyanshwor Rt	2117	4	-2	32
12	Airport to Gyaneshwor Th	2947	5.5	6	9999
13	Gyaneshwor to Airport Th	3220	6.5	8	9999
14	Dhumbarahi to Basundhara Th	5238	10	0.5	9999
15	Basundhara to Dhumbarahi Th	6208	12	4	9999
16	Gangalal to Lainchaur Th	3693	7	0.5	9999
17	Lainchaur to Gangalal Th	3483	6	-0.5	9999
18	Dhumbarahi to Gangalal Rt	2597	5	0.5	21
19	Gangalal to Basundhara Rt	1828	3.5	-0.5	23

4. Data analysis and modeling

A. *Saturation Flow Analysis*

The amount of traffic that may pass through a signal controlled intersection from a given approach depends on the available green time to the traffic and on the maximum flow of vehicles pass/cross the stop line during the green time. Once the signal changes to green, vehicles take some second to start, accelerate and attain the normal speed. After a few seconds, the queue discharges at constant rate called saturation flow (S). Thus, saturation flow is the flow, which would be obtained if there was a continuous queue of vehicles and they were passed at green time, or the saturation flow is maximum departure rate, which can be obtained when there is a queue. Saturation flow is the maximum rate of vehicle that can pass through a given intersection approach, if the signal remain green all the time. This one is the important parameter in capacity analysis of signalized intersection. Knowledge of saturation flow is essential in signal design also. Saturation flow depends upon number of different parameters. The saturation flow is generally expressed in vehicles per hour green time.

Table 4
Independent Variable Used for Saturation flow

Independent Variable For Saturation Flow(S), PCU/hr	
Variable	Variable name description
Width(w)	Width of study approach at stop line being surveyed
Gradient(G)	Approach gradient
Right Turning Radius (R)	Right turning radius of vehicles

The table 5 below gives the R- square and t-value of different model. On t-value, SNS indicates some of the parameter /variable on model are insignificant because of the value less than -1.96 or 1.96 at 5 % level of significance. The sig indicates the t-value of the variable are significant.

Table 5
R- square and t-value of different model

Model no.	Model	R square	t value
Model 1	S.F=143.769+506.247W	0.919	Sig
Model 2	S.F=143.097+510.162W-22.045G	0.921	Sig
Model 3	S.F=135.271+487.434W-28.439G+0.028R	0.930	Sig
Model 4	S.F=136.771+484.363W+0.025R	0.927	Sig
Model 5	S.F=2846.448+0.129R	0.241	Sig
Note: Sig= all significant , SNS= some non-significant			

5. Validation of the models

Table 6
Result from validation of model from same intersection data

S.No.	Model	R square	F-value	T- value	Correlation factor (r)
1	For saturation flow model with lane width (Model 1)	0.792	0.000	Significance	0.813
2	For saturation flow with lane width and gradient (Model 2)	0.795	0.000	Significance	0.892
3	For saturation flow with lane width, gradient and turning radius (Model 3)	0.812	0.000	Significance	0.901

The process of ensuring that the model behaves as intended, usually by debugging or through animation is the verification. Verification is necessary but not the sufficient for validation hat is a model may be verified but not valid. Validation ensures that there is no significant difference between the model and the real system and that model reflects reality. Validation can be achieved through statistical analysis. Sometimes, face validity may be obtained by having the model reviewed and supported by an expert.

From the above models, model 3 is the best model to calculate the saturation flow obtained from present study because r-square value is more than other models

- Adjustment R-squared value= 0.792 (i.e. 79.2) of the variance of original field data is explained by the variance of field data from the multi linear regression
- Significance F= 0.000 (i.e. there is 0% possibility that the regression output was merely a chance occurrence
- T value = all parameter is significant because t- value is either less than -1.96 or greater than 1.96 at 5% level of significance.
- Regression equation
  Predicted value = 41.067 + 0.878 * observed value

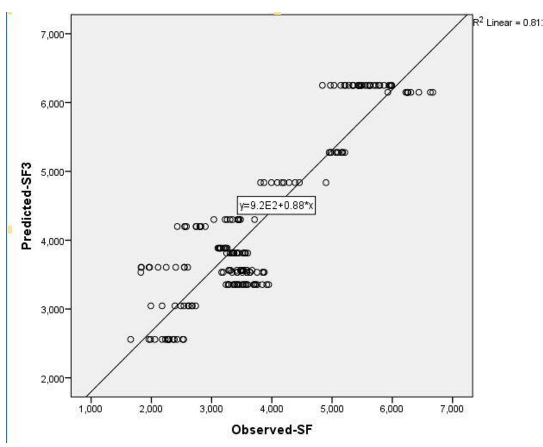

Fig. 2. Validation of saturation flow model

6. Conclusions and recommendation

A. Conclusion

- The regression model developed for saturation flow rate is mainly based on approach width, approach gradient and right turn radius.
- Model 1 SF= 143.769+506.247W, Model 2 SF= 143.097+510.162W-22.045G and Model 3 SF=135.371+487.434W-28.439G+0.028R as a best model.
- The base saturation flow was taken as 1900 PCU /hr. HCM 2000.
- The adjustment factor for width (FW), is given by FW= 1+(W-3.5)/3.862, where W is the width of lane.
- The adjustment factor for right turn radius (FR) = 1+14.836*r/1000, where r is the right turning radius of right turning vehicles.
- It is found that the lane width and right turning radius has positive effect and saturation flow and the gradient has negative impact on saturation flow rate.

By introducing of the adjustment factors to the proposed model it can give better realistic field values, which will be helpful in obtaining the capacity at signalized intersections which in turn help to assess the level of service (LOS) at signalized intersections, specially under heterogeneous traffic condition.

B. Recommendation

- The regression model developed for saturation flow is focused on traffic data collected for 3 signalized intersections of Kathmandu city. The further study needs to be done considering more intersections.
- Saturation flow depends on various factors. In this study, only effect of lane width, approach gradient and right turn radius where considered. All these factors need to studied and developed new model. Taking into account maximum variables.
- The saturation flow model is developed only considering through and right moving vehicles, the effect of left turn vehicles on saturation flow must be checked.
- The effect of grade is shown in all selected parameters. It should be checked for the same lane width different gradient.
- The effect of right turnings should be checked for only right turning movement apart from through movement for better result.
- In present study, PCU is considered from JICA survey report 2012 of Kathmandu City. It should be obtained from the individual intersections.

References

[1] HCM (20000) Highway Capacity Manual, Transport Research Board, USA.
[2] Shrestha, S. and Marsani, A (2014) Development of Saturation Flow and Delay Model at Signalized Intersection of Kathmandu. *proceedings of IOE Graduate Conference*, Kathmandu,387-392.
[3] Alam, Md. J. B., Osra, K. A., Al-Bar, H.O. and Zahran, S. Z, (2010) "Signalized Intersection Capacity Adjustment Factors for Makkah, Saudi Arabia," *Canadian Journal of Transportation*, 4,54-66.
[4] Shao, C. Q., Rong, J. and Liu, X.M, (2011), "Study on the Saturation Flow Rate and its Influence Factors at Signalized Intersections in China," 6th *International Symposium on Highway Capacity and Quality of Service Stockholm*, Sweden
[5] B. G. Savitha, H. S. Jagdish and H. S. Satish and T. Sundararajan (2017), "Study on Geometric Factors Influencing Saturation Flow Rate at Signalized Intersections Under Heterogeneous Traffic Conditions," *Journal of Transportation Technologies*, 7, 83-94.
[6] Shao C. and Liu X. (2012), "Estimation of Saturation Flow Rates at Signalized Intersection," Hindawi Publishing Corporation Discrete Dynamics in Nature and Society, Cairo.
[7] IRC: SP Guidelines for the Design of at Grade Intersection in Rural and Urban Areas. Indian Road Congress.
[8] Chand S., Jain Gupta, N and Velmurugan, S, (2016), "Development of Saturation Flow Model at Signalized Intersection," *World Conference on Transport Research – WCTR2016, Shanghai.*

[9] Chen A. P., Nakamura H., and Asano M, (2011), "Saturation Flow Rate Analysis for Shared Left- Turn Lane at Signalized Intersection in Japan," *6th International Symposium on Highway Capacity and Quality of Service Stockholm*, Sweden.
[10] Preethi, P. and Ashalatha, R, (2017), "Modeling Saturation Flow Rate and Right Turn Adjustment Factor Using Area Occupancy Concept," *Case Study on Transport Policy* ,6, 63-71, Kerala.