Saturation Flow Analysis

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Abstract—Minimal work has been done in the past on calibration of the parameters for saturation flow rate used in traffic control of signalized intersections. This paper discusses a saturation flow study conducted in Ahmedabad city, the commercial city of Gujarat, which lies in the west of India. Using linear regression analysis, of saturation flow rate for four signalized intersections has been studied. Base saturation flow rate have been calculated. The results confirm that the methodology for saturation flow rates, put forward by highway capacity manual (HCM) can also be used in India. However, parameters should be systematically calibrated, based upon widespread study, before they can be used effectively in the practice of traffic control in India.

Index Terms:- volume, saturation flow rate, speed, density, signalized intersections, linear regression analysis, traffic control.

I. INTRODUCTION

Saturation flow is a very important road traffic performance measure of the maximum rate of flow of traffic. It is used extensively in signalized intersection control and design. Saturation flow describes the number of passenger car units (pcu) in a dense flow of traffic for a specific intersection lane group. In other words, if an intersection's approach signal were to stay green for an entire hour and the flow of traffic through this intersection were as dense as could be expected, the saturation flow rate would be the amount of passenger car units that passed through this intersection during that hour.

According to the Highway Capacity Manual (TRB, 2000) there are various factors that influence the value of saturation flow at an intersection. A few of these were investigated during this study and will be discussed later.

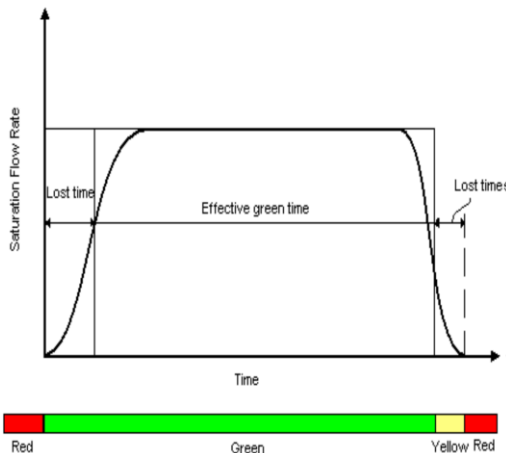

Fig. 1: The flow of traffic during the green period from a saturated approach

Note from the figure that as the traffic signal shows green, there is first a very short gap as the first driver reacts to the signal change. The rate of vehicles crossing the stop line increases as vehicles accelerate to the speed determined by the cars they are following. Vehicles soon reach a state where they are following one another at a constant headway. This constant rate is represented by the plateau of this flow profile. In a saturated junction, the queue formed in the red time will be too long to clear in the green period and so cars will follow each other at constant spacing during the green period. The flow rate will start dropping at an increasing rate when the signals are in yellow time and then stop when the signals turn red. The saturation flow is calculated by making the curved profile into a rectangle from which the dimensions can be measured. This is achieved by identifying lost time and effective green time. The lost time is the time from the start of green to a point where vehicles are flowing at half the maximum flow plus the time from where vehicles are flowing at half the maximum flow at the end of saturation to the beginning of red time.

However, to determine the saturation flow rate from time measurements taken in the field the following equation is used:

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

Where:
s = saturation flow rate;
3600 = number of seconds per hour;
hs = saturation headway.

II. TERMINOLOGY AND KEY DEFINITIONS

A. *Basic Concepts Form Uninterrupted-Flow Facilities:* volume, flow rate, speed, density, headway, and capacity Volume and flow rate are two measures that quantify the amount of traffic passing a point on a lane or roadway during a given time interval. These terms are defined as follows:

1) *Volume:* The total number of vehicles that pass over a given point or section of a lane or roadway during a given time interval; volumes can be expressed in terms of annual, daily, hourly, or sub hourly periods.

2) *Flow rate:* The equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval of less than 1 h, usually 15 minute. Volume and flow are variables that quantify demand, that is, the number of vehicle occupants or drivers (usually expressed as the number of vehicles) who desire to use a given facility during a specific time period. Congestion can influence demand, and observed volumes sometimes reflect capacity constraints rather than true demand.

3) *Speed:* Speed is defined as a rate of motion expressed as distance per unit of time, generally
as kilometers per hour (km/h).

4) *Density:* Density is the number of vehicles (or pedestrians) occupying a given length of a lane
or roadway at a particular instant. For the computations in this manual, density is averaged over time and is usually

expressed as vehicles per kilometer (veh/km) or passenger cars per kilometer (pc/km).

$$D = \frac{V}{S}$$

Where

v = flow rate (veh/h),
S = average travel speed (km/h), and
D = density (veh/km).

5) *Average Running Speed:* A traffic stream measure based on the observation of Average running speed vehicle travel times traversing a section of highway of known length. It is the length of the segment divided by the average running time of vehicles to traverse the segment. Running time includes only time that vehicles are in motion.

6) *Average Travel Speed:* A traffic stream measure based on travel time observed on an Average travel speed known length of highway. It is the length of the segment divided by the average travel time of vehicles traversing the segment, including all stopped delay times. It is also a space mean speed.

7) *Space Mean Speed:* A statistical term denoting an average speed based on the Space mean speed average travel time of vehicles to traverse a segment of roadway. It is called a space.

Mean speed because the average travel time weights the average to the time each vehicle Spends in the defined roadway segment or space.

8) *Time Mean Speed:* The arithmetic average of speeds of vehicles observed passing a Time mean speed point on a highway; also referred to as the average spot speed. The individual speeds of vehicles passing a point are recorded and averaged arithmetically.

9) *Free-Flow Speed:* The average speed of vehicles on a given facility, measured under Free-flow speed low-volume conditions, when drivers tend to drive at their desired speed and are not constrained by control delay.

10) *Clearance(c):* Clearance is similar to spacing, except that the clearance is the distance between the rear bumper of the leading vehicle and the front bumper of the following vehicle. The clearance is equivalent to the spacing minus the length of the leading vehicle. Clearance, like spacing, is usually reported in units of feet or meters.

11) *Gap (g):* Gap is very similar to headway, except that it is a measure of the time that elapses between the departure of the first vehicle and the arrival of the second at the designated test point. Gap is a measure of the time between the rear bumper of the first vehicle and the front bumper of the second vehicle, where headway focuses on front-to-front times. Gap is usually reported in units of seconds.

12) *Spacing(s):* Spacing is the physical distance, usually reported in feet or meters, between the front bumper of the leading vehicle and the front bumper of the following vehicle. Spacing complements headway, as it describes the same space in another way. Spacing is the product of speed and headway.

13) Headway (h): Headway is a measure of the temporal space between two vehicles. Specifically, the headway is the time that elapses between the arrival of the leading vehicle and the following vehicle at the designated test point. You can measure the headway between two vehicles by starting a chronograph when the front bumper of the first vehicle crosses the selected point, and subsequently recording the time that the second vehicle's front bumper crosses over the designated point. Headway is usually reported in units of seconds.

14) *Peak Hour Factor (PHF):* The ratio of the hourly flow rate (q60) divided by the peak 15 minute rate of flow expressed as an hourly flow (q_{15}). PHF= q_{60}/ q_{15}.

15) Cycle: One complete sequence of signal indications

16) *Cycle Length (Co):* Total time for the signal to complete one cycle, expressed in seconds

17) *Phase*: Part of cycle allocated to any combination of traffic movements receiving the right of way simultaneously during one or more interval.

18) *Interval*: Period of time during which all signal indications remain constant

19) *Change Interval (Y):* The "yellow" and /or "all-red" intervals, which occur at the end of a phase to provide for clearance of the intersection before conflicting movement are released also known as "Amber Period".

20) *Green Time (G):* Time within a given phase during which the "green" indication is shown, stated in seconds.

21) *Lost Time:* Time during which the intersection is not effectively used by any movement, which occur during the change and clearance intervals (when the intersection is cleared) and at the beginning of each phase as the first few vehicles in a standing queue experience start-up delays.

22) Effective Green Time (g): Time during which a given phase is effectively available for stable moving platoons of vehicles in the permitted movements, generally taken to be the green time plus the change and clearance interval minus the lost time for the designated movement, stated in seconds.

23) *Green Ratio (g/C*): Ratio of effective green time to the cycle time.

24) *Effective Red (R):* Time during which a given movement or set of movements is effectively not permitted to occur, the cycle length minus the effective green time, stated in seconds.

III. Factors Affecting The Saturated Flow

– Vehicle mix; A multitude of different types of vehicles, motorized and non-motorized, with different operating performances;
– Driver behavior - poor lane discipline and observation of traffic signals; Public transport - varied mix of bus types, stopping places and driving styles
– Roadside activity - roadside land uses generate parking and non-transport activities that reduce effective lane width The study done in Stellenbosch investigated the following possible influences on saturation flow:
– Speed limits - intersections with different speed limits namely 60 km/h and 80 km/h were observed;
– Gradient - intersections on different gradients were observed for traffic flow up hill and traffic flow downhill;
– Right-turn movements - intersections with a leading green-phase for right turning movements were observed;
– Number of through lanes.

IV. Traffic Signal Needs Studies

The overall objective of traffic signal control is to provide an equitable balance of safe and efficient movements of traffic and pedestrian volumes through the intersection. Although most of the steps in conducting a traffic signal needs study are quantitative, the final determination of recommending whether traffic signal controls should be provided at a particular location involves a qualitative assessment which requires engineering judgment. If the particular location being studied satisfies one or more of the MUTOD warrants, one of the most important qualitative assessments the traffic engineer should consider before justifying traffic signal control is a remedy that is less restrictive than signalizing the intersection.

Some of the less restrictive remedies that should be considered are:

- They provide orderly movement of traffic and increase the traffic handling capacity of most of the intersections at grade.
- They reduce certain types of accidents, notably the right angled collisions.
- Pedestrians can cross the roads safely at the signalized intersections.
- Proper coordinated signal system provides reasonable speed along the major road traffic
- Signal provide a chance to crossing traffic of minor road to cross the path of continuous flow of traffic stream at reasonable intervals of time.
- Automatic traffic signal may work out to be economical when compared to manual control.
- The quality of traffic flow is improved by forming compact platoons of vehicles, all the vehicles move at approximately at the same speed.

A. *Measurement Methods*

Followings are the Method of saturation flow

1) *Road Research Laboratory Method*

This is a manual method for data collection for saturation flow estimation. According to this method, green plus amber time is to be divided in to short interval such as of 0.1 minute (6 seconds). All those vehicles whose rear wheels cross the stop line during each 0. 1 min intervals are to be counted. The flows in saturated intervals, which are free from lost time, are averaged to get saturation flow it is seen that saturation flows in the first and last intervals are affected by driver's starting delay at the start of amber and stopping at the lapse of green time, respectively. The saturation flow observed in those intervals which are free from lost time, is to be compared with the saturation flow in the first and last intervals to get the initial and final lost time, respectively. Special forms are to be used at site during experiment. Two "split second", stopwatches are required to record the data on the forms. These watches should be graduated in tenth and hundredths of a minute. All the timings should be recorded to nearest 0.01 min. Watches are to be synchronized before the start of data collection. This method is simplest but it has a drawback, causing difficulty in classifying the different types of vehicles and recording the various turning movements. Therefore, it requires more manpower, which is uneconomical.

2) *Recorder Method*

In this method, the data should be recorded either on paper tape or on a paper chart driven at a constant speed. All the information relevant to saturation flow should be recorded on to paper tape or chart. The analysis involves the manual work of measuring the distance on the tape or on the chart to know the time interval. Therefore some errors are inevitable due to variation in the observer's reaction time. The following are the various types of the recorder method, which have been used by various researchers in earlier studies.

3) *Typewriter Method*

This method was developed by Helim in 1957-58, during the study of saturation flow at light controlled intersection in Newcastle upon Tyon and GateShied. During the observation vehicles were classified into four groups, light vehicles, heavy vehicles, heavy commercial vehicles and public service vehicles. For the data collection a modified typewriter was used. With the use of a modified

Type writer, measurements were within a limit of 1/10 seconds; this enabled the data collection suitable for individual vehicle analysis as well as for whole traffic stream.

4) *The Rustrak Four Channel Event Recorder Method*

This method was developed while collecting data for saturation flow and lost time in Aberdeen by using the same procedure of Road Research Laboratory method, as highlighted above, but permitting simultaneous classified counts of four traffic streams and timing of signal cycles.

5) *Battery Operated Cassette Tape Recorder Method*

This method was used by Miller, for data collection in seven main cities of Australia. It was similar to Road Research Laboratory method. The only difference being that in the case of Road Research Laboratory method the traffic data were recorded on forms at the sites whereas in this method, the data were recorded on the tape and then abstracted by playing back the recorded cassette in the

Laboratory. All the information concerned with the data, i.e., vehicle types, turning movements, change in signal phase and all the vehicles that cross the stop line during these short intervals, were recorded.

6) *Time Lapse Photography Method*

Time laps cinematography is an old technique and was developed extensively for many forms of engineering data collection. Each picture or frame might be considered as a pictorial description of position of those vehicles, which are within the field of camera view at the instant of exposure. By comparing the positions of the individual vehicles on consecutive frames of the film distance which these vehicles had been moved could be estimated and hence these various parameters of traffic flow could be evaluated.

For precise measurement, a series of the equidistant markings along the side of carriage way could be marked before the filming commenced. This marking would come up on the film through which the positions of the vehicles could be determined. Time laps photography has proved a useful tool for data collection in the traffic engineering for studying the traffic behavior. The drawback in this method is the inability of the equipment to operate in excess of four frames per second with an accurate time base as discovered by Ashworth.

7) *Video Tape Recorder Method*

During the last three decades video tape recorder has proved to be the most popular alternative method of recording traffic behavior. This equipment has provided more satisfactory results than the time laps photography in its early stage. During the data collection at the site the portable video recording camera and number generator is used to super impose the time based on the recorded traffic events.

Nowadays cameras with a built-in time base recording are available, that can measure the time in fraction of a second. While recording, the camera should be so placed that the reference line should be visible and every traffic event should be abstracted easily. This instrument has proved satisfactory, but there exists one disadvantage of blurring image, which is less evident in time laps photography. Due to the availability of slow motion facility in the video cassette player, it appears to be better than the other methods because of accuracy and required manpower. The advocacy of this method is proved by many researchers.

8) Use of Mobile Traffic Laboratory

This is an advance version of use of video recording method. This method was used by Cartagena and Tarko and is explained in their research paper .In this method a digital video recorder and cameras on a 45-ft mast were used for recoding traffic queues and signal displays. The mobile traffic laboratory was parked near the intersection where traffic operations were not affected by its presence.

Fig. 2: Typical layout of field data collection equipment setup

Fig. 3: Typical layout of field data collection equipment setup

V. SATURATION FLOW ANALYSIS

Saturation flow is the maximum rate of vehicular flow that can pass through a given intersection approach, during green. This is one of the important parameter in capacity analysis of signalized intersection. Saturation flow is essential parameter for signal design also. Saturation flow depends upon number of different factors. Traffic flow characteristics near intersections have been discussed in page no.2. This chapter primarily deals with field measurement of saturation flow, estimation of passenger car unit (PCU) values.

VI. STUDY AREA

- Income tax intersection
- Shyamal intersection
- Jodhpur intersection
- Shastri nagar intersection
- Traffic Composition at Selected Intersection Approaches

A. *Income Tax Intersection*

This is four-legged four phase intersection. During peak hours (morning peak), the intersection gets over saturate (Demand more than capacity). The road surface condition at study approaches is fairly good, affecting the speed of vehicles. Traffic flow was recorded for the intersection, coming from AEC intersection, Paldi intersection, Elish Bridge and Shastri nagar. Traffic consists of car, auto-rickshaw, bus, two wheelers, bicycle and others.

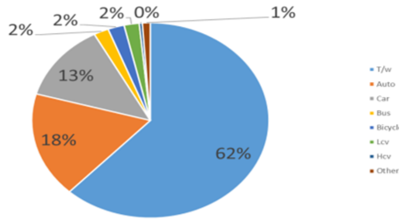

Fig. 4:

B. *Shyamal Intersection*

This is four-legged three phase intersection. During peak hours (morning peak), the intersection gets over saturate (Demand more than capacity). The road surface condition at study approaches is fairly good, affecting the speed of vehicles. Traffic flow was recorded for the intersection, coming from Shastri nagar intersection, Andhjanmandal intersection, and Sivranjani Intersection. Traffic consists of car, auto-rickshaw, bus, two wheelers and bicycle LCV, HCV and Others.

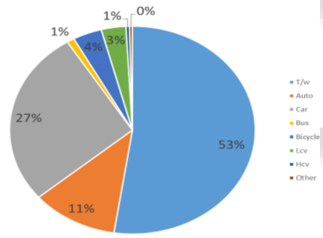

Fig. 5:

C. *Jodhpur Intersection:*

This is four-legged four phase intersection. During peak hours (morning peak), the intersection gets over saturate (Demand more than capacity). The road surface condition at study approaches is fairly good, affecting the speed of vehicles. Traffic flow was recorded for the intersection, coming from University intersection, Sivranjani intersection. Traffic consists of car, auto-rickshaw, bus, two wheelers and bicycle and others.

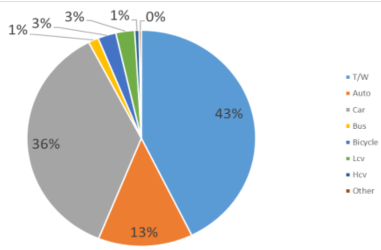

Fig. 6:

D. *Shastri Nagar Intersection*

This is four-legged four phase intersection. During peak hours (evening peak), the intersection gets over saturate (Demand more than capacity). The road surface condition at study approaches is fairly good, affecting the speed of vehicles. Traffic flow was recorded for the intersection, coming from Sivranjani intersection, Anjanmandal intersection. Traffic consists of car, auto-rickshaw, bus, two wheelers, LCV, HCV and bicycle and others.

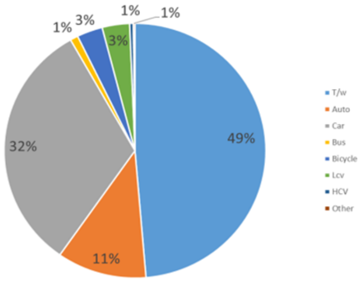

Fig. 7:

E. *Field Measurement of Saturation Flow*

The average headway method based on time headway of departing vehicles cannot be used for non-lane based traffic condition, because in non-lane based traffic flow, headways are difficult to observe, as vehicles do not move in lanes. Traffic is analyzed on the basis of total width of approach and hence, the option of vehicle counting is adopted. Saturation flow is calculated independently for each observed saturation period and then averaged over observed cycles. All counted vehicles are added and sum is divided by saturation period to get saturation flow in vehicles per hour.

Table shows the data of field measurement of saturation flow at Jodhpur Intersection

Jodhpur Intersection

Approach	**North**	**South**	**East**	**West**
Width(m)	6	6	7	7
TW (%)	58	46	41	42
Auto (%)	10	20	11	12
Car (%)	23	25	40	37
Bus (%)	2	1	1	2
Bicycle (%)	3	3	2	3
LCV (%)	2	3	3	2
HCV (%)	1	1	2	1
Others (%)	1	1	0	1
PCU/ hour	6322	4745	10423	8906
Gradient (%)	8.58	7.12	7.45	2.4

Table shows the data of field measurement of saturation flow at Income Tax Intersection

Income Tax Intersection

Approach	**South**	**West**	**North**	**East**
Width(m)	9.5	9.5	9.5	10.5
TW (%)	55	59	69	68
Auto (%)	21	17	15	2
Car (%)	16	15	18	17
Bus (%)	3	4	5	6
Bicycle (%)	2	2	2	3
LCV (%)	2	2	2	2
HCV (%)	1	1	2	1.5
Others (%)	0	0	0	0.5
PCU/ hour	10581	9993	9674	10919
Gradient (%)	4.72	5.36	4.01	3.94

Table shows the data of field measurement of saturation flow at Shyamal Intersection

Shyamal Intersection

Approach	**South**	**North**	**East**	**West**
Width(m)	9.5	9.5	9.5	9.5
TW (%)	44	58	48	56
Auto (%)	15	10	11	11
Car (%)	27	23	26	23
Bus (%)	1	2	3	1
Bicycle (%)	6	3	5	3
LCV (%)	5	2	3	4
HCV (%)	1	1	1	1
Others (%)	1	1	1	1
PCU/ hour	7762	6395	8344	8052
Gradient (%)	2.52	2.44	1.78	2.68

Table shows the data of field measurement of saturation flow at Shastri Nagar Intersection

Shastri Nagar Intersection

	North	**South**	**East**	**West**
Width(m)	7	9	6	7.5
TW (%)	55	43	54	47
Auto (%)	11	11	12	10
Car (%)	23	38	24	29
Bus (%)	1	2	1	2
Bicycle (%)	3	1	3	5
LCV (%)	4	3	4	5
HCV (%)	2	1	1	1
Others (%)	1	1	1	1
PCU/ hour	7221	6705	7504	6189
Gradient (%)	8.58	4.51	5.34	3

VII. STUDY AREA:

Followings are the study area.

– IncomeTax intersection
– Shyaml intersection
– Shastri nagar intersection
– Jodhpur intersection

VIII. CONCLUSIONS

In this study it was found that:

– Saturation flow rates in South Africa (Stellenbosch at least) are much higher than in other countries. This could be an indication of the aggressiveness of local drivers;

- An increase in the speed limit leads to an increase in the saturation flow rate; an increase (from 1 to 2) in the number of through lanes leads to an increase in the saturation flow rate;
- An increase in the gradient leads to a decrease in the saturation flow rate; and
- The saturation flow rate on exclusive single right turn lanes with their own phase can even be greater than that of a single through lane. This could be ascribed to traffic pressure.
- The effects of speed limit, gradient and number of through lanes on the saturation flow rate are much greater locally than in the USA.

REFERENCES

[1] Measuring Technology and Mechatronics Automation, 2009. ICMTMA '09. International Conference on (Volume:3)
[2] C. J. Bester and W.L. Meyers Department of Civil Engineering, University of Stellenbosch, Private Bag X1, MATIELAND 7602
[3] Transportation Research Board, Highway Capacity Manual 2000, National Research Council, Washington, DC, USA, 2000.
[4] Department of Civil Engineering, University of Stellenbosch, Private Bag X1, MATIELAND 7602
[5] Turner, J and G Harahap, 1993. Simplified saturation flow data collection methods. In: CODATU VI Conference on the Development and Planning of Urban Transport, Tunis, February 1993.
[6] Modification of Webster's delay formula using modified saturation flow model for non-lane based heterogeneous traffic condition N.G. Raval & P.J. Gundaliya
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