Development of Saturation Flow Rate Model due to Users' Violation Impact at Signalized Intersection

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Abstract: Intersections are the points where two or more roads converge at same or different elevations which plays important role in quality of urban transportation network. Signals are provided at intersections for safe movement of large volume of vehicles. For the estimation of performance of intersection behaviour of users plays important role as conflict between users leads to decrease in green phase time which ultimately leads to reduction in capacity of intersection. Saturation flow rate and PCU are important to consider for capacity, design and operation of signalized intersection as India have heterogeneous traffic conditions. Saturation flow rate depends on geometric conditions, flow characteristics, type of movement and traffic behaviour. Violations by users are the problematic traffic behaviours at signalized intersections which lead to reduction in saturation flow rate and capacity and increased delay. The main purpose this study is to develop saturation flow rate model due to users' violation impact at signalized intersection at Ahmadabad. Data was collected through videography. Multiple Linear regression model of saturation flow rate was formed considering impact of user's violations. The results showed the significant effect of users' violations on the saturation flow rate, and the effect of each of the variables was evaluated by the use of proposed model. Result show that On average, one unit increase in the violations by pedestrians at entrance crosswalk (per hour) leads to saturation flow rate decreases by 1.284 unit.On average, one unit increase in the violations by pedestrians at exit crosswalk (per hour) leads to saturation flow decreases by 0.955 unit. Further, On average one unit increase in the traffic light violations by vehicles (per hour) leads to saturation flow decreases by 0.543 unit. Thus it is recommended that Traffic rules for pedestrian movement at intersection should be enforced and they should be fined if not followed.

Index Terms: **Intersection Capacity, Road User's Violation, Saturation Flow Rate, Traffic Behaviour**

I. INTRODUCTION

An intersection is a location where two or more roads carrying traffic streams in different directions cross each other at different or same elevation. In the case of developing countries like India, intersection at the same grade is common phenomenon as the other one is very expensive. However, they provide more safety and least delay comparatively. The space which is common to all these roads is generally known as the intersection. At such a location, different traffic streams compete with one another for the use of that common space at the intersection. Traffic signals are mainly used to control traffic movements and stop conflicts among them in urban and semi urban areas of the developing and developed countries.

For the estimation of performance of intersection behaviour of users plays important role as conflict between users leads to decrease in green phase time which ultimately leads to reduction in capacity of intersection. The assessment of performance of signalized intersections often require the determination of capacity of approach lane or lane group and the intersection clearing speed of queued vehicle during queue discharge. The evaluation of capacity at signalized intersection is an important component in the planning, design, operation and management of transportation system. Presently, the methodologies available for the estimation of capacity of signalized intersections are based on the concept of saturation flow (s).

Saturation flow describes the number of passenger car units (PCU) in a dense flow of traffic for a specific intersection lane group. In a mixed traffic condition, the interaction of various classes of vehicles along a road creates many problems to the traffic engineers and Planners due to the wide variation in their physical and operating characteristics. The non uniformity in the static and dynamic characteristics of the vehicles is normally taken into account by converting all vehicles in terms of a common unit known as Passenger Car Unit (PCU). The design, the capacity and operation of a signalized intersection critically depend on and passenger car unit (PCU) and saturation flow.

According to HCM 2010, saturation flow can be defined as the maximum hourly flow rate at which queued vehicles can cross the intersection under existing traffic condition, assuming that green signal is available all the time and no time loss are experienced by the vehicles. The capacity and level of service of an intersection can be assessed by saturation flow. HCM 2010 has introduced a procedure to estimate saturation flow, assuming that the vehicles follow lane discipline. However, in developing countries like India, traffic is heterogeneous in nature, and very poor lane discipline is maintained. Due to fundamental variation in traffic characteristics and driver behaviour, the models developed in USA and UK for estimating saturation flow are not applicable for developing countries like India. Saturation flow rate is a major factor in determination of capacity of signalized intersections, and depends on various factors such as geometric characteristics, flow characteristics, type of movement and traffic behaviour.

Users' Violation Scenario

Violations by users are the problematic traffic behaviours at signalized intersections which lead to reduction in saturation flow rate and capacity and increased delay. Pedestrians are the most vulnerable road users; they are exposed to traffic environments and lack sufficient Protection in the event of a crash, especially at signalized intersections. Previous studies have examined pedestrian noncompliance behaviours at signalized Intersections[9]. Illegal pedestrian behaviour is a significant factor of many traffic crashes either in developing or developed countries however it is reported by the past works that the pedestrian violation rate in developing countries is particularly high. Pedestrians' violation has been associated with various factors, such as individual characteristics, road and traffic conditions, and environment factors [5]. Demographic characteristics have been found to be vital contributing factors to pedestrian red light running behaviours. Most of the previous works showed that age and gender are associated with pedestrians' red light running behaviour. Razzaghi and Zolala (2015) reported that males were more likely to run when crossing the street than women. It has been shown that females' crossing behaviour can be influenced by the presence of other pedestrians. Thus, group size was an important factor in pedestrian red light running behaviours.

It is noteworthy that a number of factors exist that may affect pedestrians red light running violation, including pedestrian characteristics, roadways features, traffic-related factors, environmental conditions, and the complex interactions between them, such as more lane number there was, the lower the pedestrian violation rate would be.

The results showed that intersection type had significant main effect on pedestrian violation. The violation rate at Cross-intersection was significantly higher than that at T-intersection. The width of road had significant effect on pedestrian violation, i.e the narrower the road, the higher the rate of violation.

II. RESEARCH OBJECTIVE

- To develop saturation flow rate model considering user's violation impact at signalized intersection.

III. STUDY AREA

Ahmedabad is fastest growing cities in the world and rapid urbanization will lead to more people migrating from different parts of the state and the country. In the metropolitan city like Ahmedabad, traffic congestion and pollution are biggest problems. In this study, traffic data was collected from Paldi cross road and Memco cross road of Ahmedabad city. All the signals are fixed-timed signals.

Site Condition at Paldi Intersection

This is four-legged four phase intersection. All four approaches are two lane separated.. During peak hours (morning and evening peak), the intersection get over saturated. Traffic flow was measured for the intersection, coming from Law Garden, Jamalpur, Vasna and Income Tax circle. Traffic consists of two-wheeler, auto, car, bus, Light Commercial vehicle (LCV) and cycle. There is AMTS bus stop between Vasna and Law garden approach so there is higher proportion of pedestrian traffic and buses at the intersection. There are two temples towards Vasna approach near the intersection. There is one school named Jain Mahavir Vidyalaya near the intersection. There is Mehendi Navaz Jung Hall towards income tax approach approximately at 140m from the intersection. There are two hotels and GSRTC bus stop towards Jamalpur and Vasna approach near the intersection.

Site Condition at Memco Intersection

This is four-legged four phase intersection. All four approaches are three lane separated. During peak hours (morning and evening peak), the intersection get over saturated. Traffic flow was measured for the intersection, coming from Naroda, Kalupur, Bapunagar and Meghaninagar. Traffic consists of two-wheeler, auto, car, bus, Light Commercial vehicle (LCV) and cycle. There is BRTS stop named "Memco Cross Road" towards Kalupur approach near the intersection. There is GSRTC bus stop towards Naroda approach near the intersection. There is Naroda Fruit Market towards Kalupur approach approximately at 500m from the intersection. There is Veer Savarkar Sports Complex towards Bapunagar approach near the intersection. There are two hotels towards Naroda and Meghaninagar approach near the intersection. There are plastic and textile industries and primary school towards Meghaninagar approach approximately 300 m from intersection. There is crockery market towards Naroda approach near the intersection.

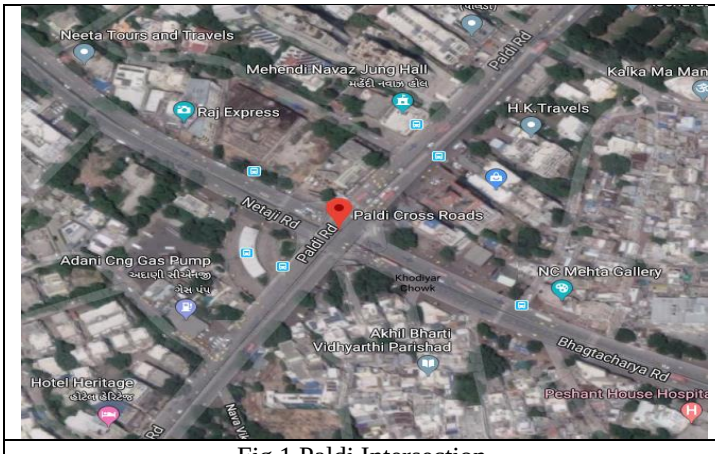

Fig.1 Paldi Intersection

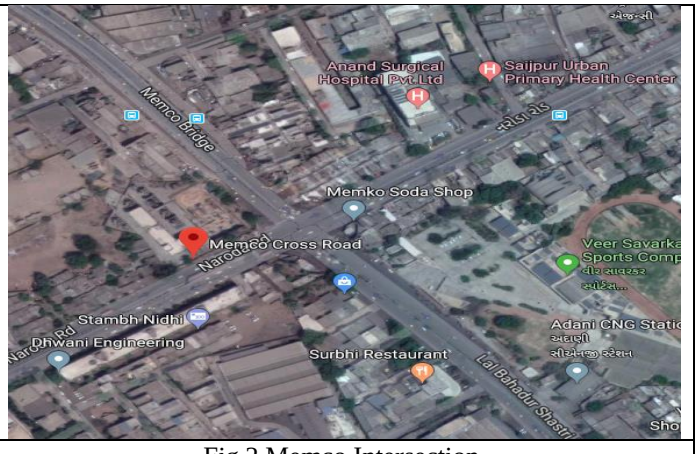

Fig.2 Memco Intersection

IV. DATA COLLECTION AND DATA ANALYSIS

The procedure for measuring traffic flow is described below. The observation point is generally stop line (desired position to stop). Start of the green was recorded. Cameras are located at upper points near intersection to capture data for peak hours at intersection. Data for traffic and violations from all approach is collected using video-graphy during morning and evening peak hours. The data are extracted from the video graphy by manually. Vehicles passing through various approaches are measured for each cycle time and recorded. User's violation observations such as no. of pedestrians violating at entrance and exit crosswalk, no of pedestrians violating by diagonal crossing, the no. of lateral movement by vehicle at any approach, the no. of vehicles violating the traffic lights and pedestrian gender are recorded.

Following data are required

1. Geometry data and signal data of study area
2. Traffic flow data and User's violation observations

Table 1: Geometry data and signal data of study area

Paldi Intersection				
Approaches	Width (m)	Red time (sec)	Green time (sec)	Yellow time (sec)
Law Garden	8.7	116	27	3
Income Tax Circle	9.4	111	32	3
Vasna	11.3	106	37	3
Jamalpur	9.3	106	37	3

Memco Intersection				
Approaches	Width (m)	Red time (sec)	Green time (sec)	Yellow time (sec)
Naroda	8.5	132	37	3
Kalupur	7.08	112	57	3
Bapunagar	10.1	141	28	3
Meghaninagar	11.7	141	28	3

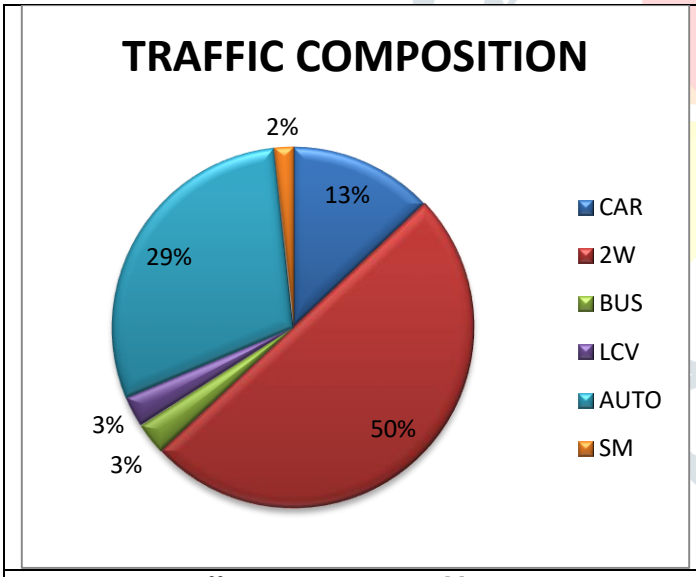

Fig.3 Traffic Composition at Paldi Intersection

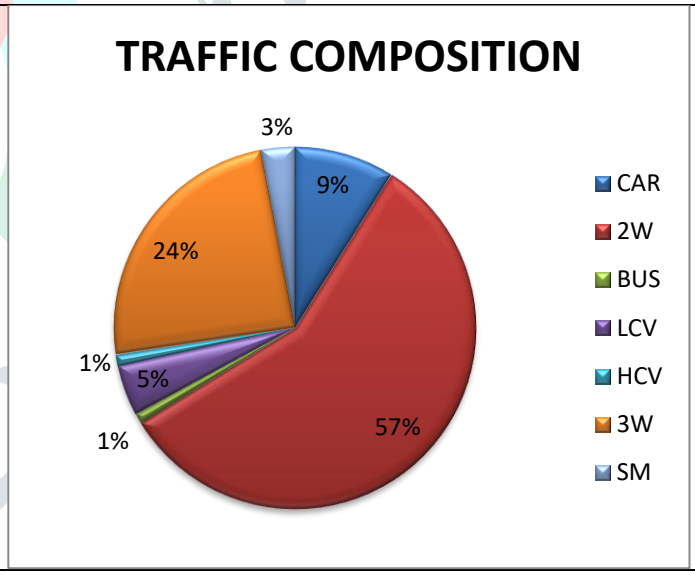

Fig.4 Traffic Composition at Memco Intersection

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User's Violation Analysis

User's violation observations includes following:

- Pedestrians violating at entrance crosswalk (on/off crosswalk)(Pent)
- Pedestrians violating at exit crosswalk(on/off crosswalk)(Pexit)
- Pedestrian's diagonal crossing(Pdia)
- Vehicle's traffic light violation(Vtlv)
- Vehicle's lateral movement(Vlm)

Fig. 5 Pedestrian's violation at entrance crosswalk(Paldi Intersection)

Fig. 6 Pedestrian's violation at entrance crosswalk(Memco Intersection)

Fig. 7 Pedestrian's violation at exit crosswalk(Paldi Intersection)

Fig. 8 Pedestrian's violation at exit crosswalk(Memco Intersection)

Fig. 9 Pedestrian's Diagonal Crossing (Paldi Intersection)

Fig. 10 Pedestrian's Diagonal Crossing (Memco Intersection)

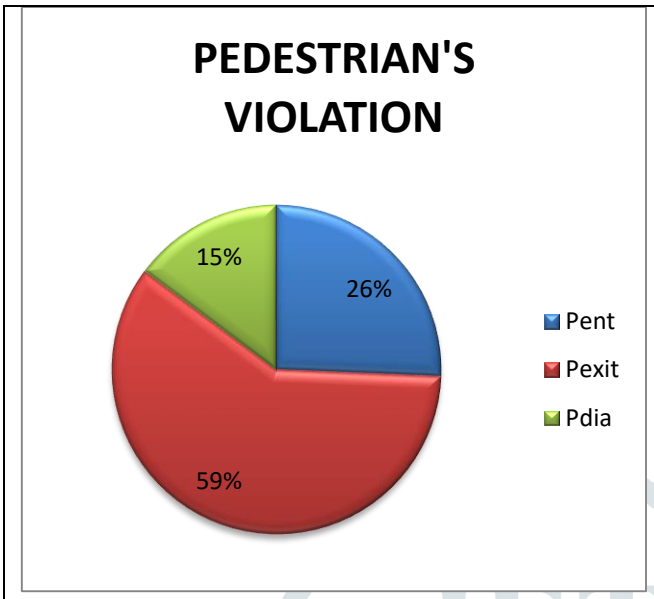

Fig. 11 Pedestrian's violation at entrance crosswalk(Paldi intersection)

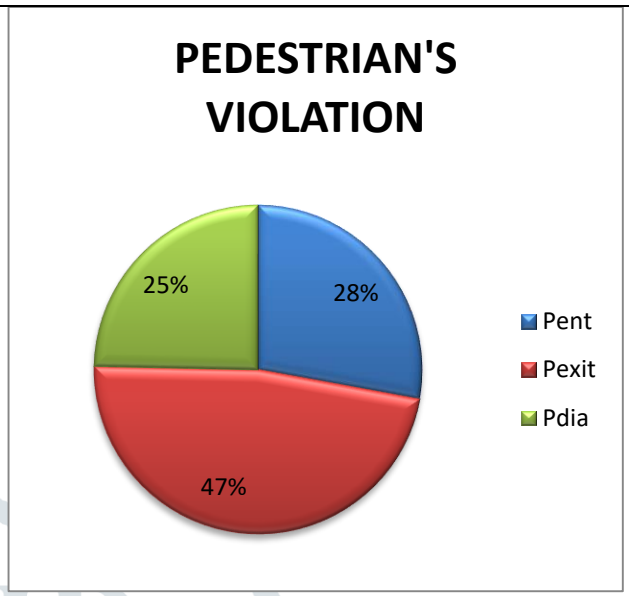

Fig. 12 Pedestrian's violation at entrance crosswalk(Memco intersection)

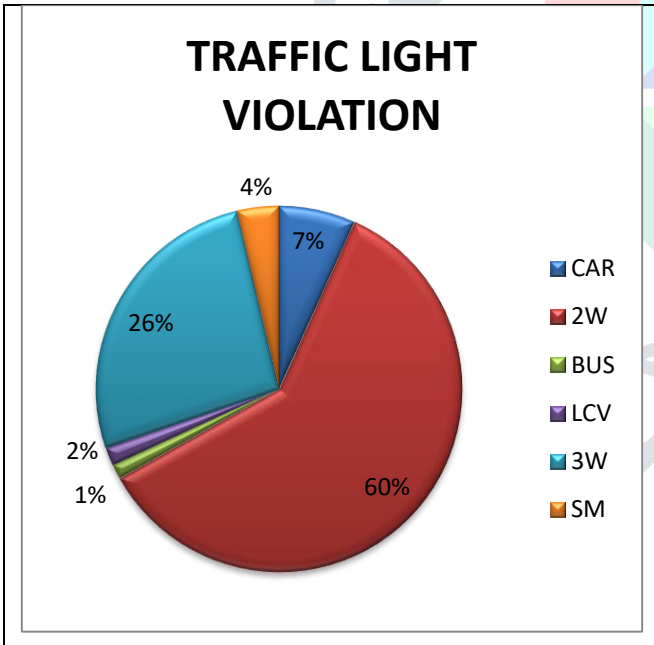

Fig. 13 Traffic light violation (Paldi Intersection)

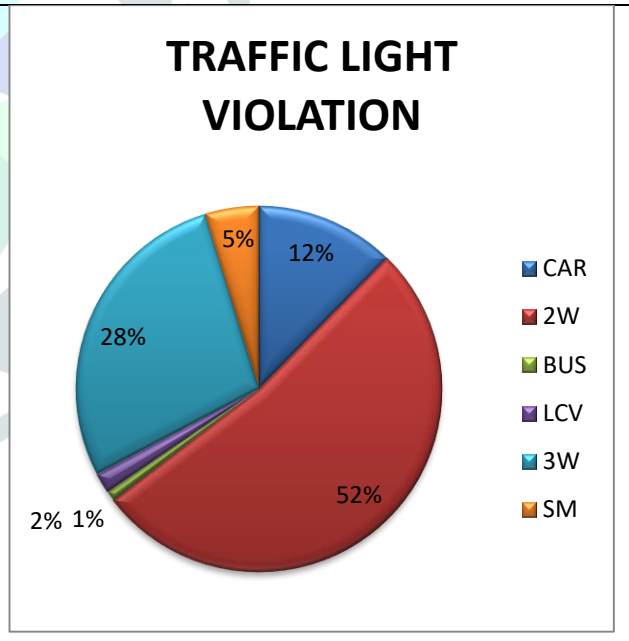

Fig. 14 Traffic light violation (Memco Intersection)

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. Saturation flow is the maximum discharge rate at which vehicles can traverse through intersection per unit time of effective green. Accurate measurement of saturation flow through an intersection is a tedious ask for traffic engineers that even with heterogeneous traffic having different geometric and operating characteristics. Various methods have been suggested throughout the literature for

distinct traffic conditions and saturation flow obtained using these methods are not similar. Saturation flow was measured by counting the number and types of vehicles when rear axle of the vehicle crossed stop line at the intersection. Start of green will be noted. Saturation flow ends when rear axle of the last vehicle from a queue crosses the stop line. Initial 3 seconds from the start of green are left to take into account start up loss time. Saturation flow for each cycle had been estimated by using the equation given below. Classified vehicle count was made for the vehicles clearing the intersection approach during saturation green time and these numbers were converted in passenger car units per hour of green time to get the SF in per hour green for each cycle.

Saturation flow rate = $\frac{N}{gs}3600$…(1.1)

Where SF = saturation flow (vehphg)

N= number of vehicles/PCU discharging during saturated green

gs = saturated green period (s)

V. FORMULATION OF SATURATION FLOW RATE MODEL

In this section, the attempt was made to apply the mathematical (statistical) concepts to develop a model which can express the saturation flow rate in terms of some parameters. The variables that were shown to have significant influences on measuring the saturation flow rate were traffic composition, violation variables and approach width. The generalized saturation flow rate model suggested by this study is below:

SF=f (traffic Composition, Violation Variables, Approach Width)

Where SF= saturation flow rate (PCU/hr)

- Traffic composition variables, Violation Variables and geometric parameter are listed below:
  a. X1= Percentage of 2 wheelers
  b. X2= Percentage of 3 wheelers
  c. X3= Percentage of Car
  d. X4= Percentage of LCV
  e. X5= Percentage of Bus
  f. X6= Percentage of Slow Moving Vehicle
  g. X7= No of pedestrians violating at entrance cross walk (no./hr)
  h. X8= No of pedestrians violating at exit cross walk (no./hr)
  i. X9= No of pedestrians crossing diagonally (no./hr)
  j. X10= No of vehicle's traffic light violation (no./hr)
  k. X11= No of vehicle's lateral movement (no./hr)
  l. X12= Approach width(m)

SF = 5425.98 + 65.096 (2W) + 79.43 (3W) + 58.524 (CAR) -108.532 (LCV)-86.706 (BUS)-0.912 (SM)-1.284 (Pent)-0.955 (Pexit)-0.101 (Pdia)-0.543 (Vtlv)-0.553 (Vlm) + 213.814(AW)……(R^2=0.781)

Where SF is saturation flow rate in (PCU/hr) and 2W, 3W, CAR, LCV, BUS, SM are in percentage. Violation variables Pent, Pexit, Pdia, Vtlv, Vlm are in (numbers/hr) and approach width is in meter.

VI. VALIDATION OF MODEL WITH RESPECT TO FIELD DATA

Saturation flow rate model has been developed using 70% of observed data. Therefore validation of model has been carried out using remaining 30% of data directly through SPSS software. Relationship between Predicted values of 30% data through above model and observed values are obtained and plotted as under:

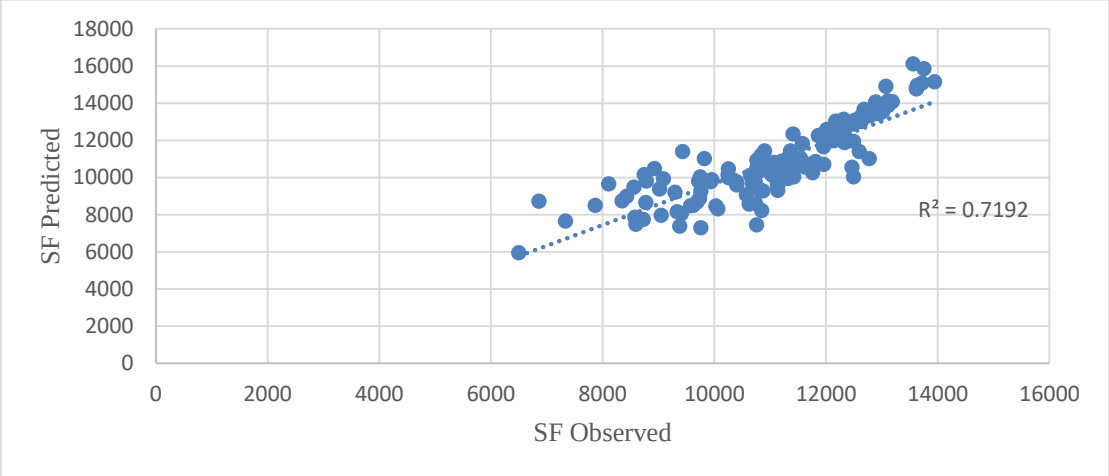

Fig. 15 Comparison of SF predicted and SF observed

The plot of estimated saturation flows against observed values shows much closeness to the diagonal line. This shows that the model can estimate saturation flows with reasonable accuracy, and can hence be used for further analysis. Considering the wide variation in the geometric and the traffic movement characteristics across intersections, it can be assumed that the proposed saturation flow model gives reasonably good predictions.

VII. CONCLUSION

The main objective of the study is to develop saturation flow rate model to represent heterogeneous traffic conditions considering user's violation impact. The present study is focused on modelling of saturation flow using traffic flow video captured data for peak hour in morning and evening on intersections of the Ahmedabad city. In this study, using multiple linear regression model, the effect of each of the factors, including violations occurred by pedestrians and motorcyclists while passing traffic light, and drivers' lateral movement on saturation flow rate were assessed. The results showed the significant effect of users' violations on the saturation flow rate, and the effect of each of the variables was evaluated by the use of proposed model.

Following are the important conclusions that are drawn from the present study.

- From the above study, it is come to know that the model developed give the saturation flow rate fairly well and this model can used to estimate saturation flow at any signalized intersections knowing approach width, traffic composition and violation observations.
- From study, it was found that as pedestrian's violation increases at entrance crosswalk, saturation flow decreases. On average, one unit increase in the violations by pedestrians at entrance crosswalk (per hour) leads to saturation flow rate decreases by 1.284 unit.
- From study, it was found that as pedestrian's violation increases at exit crosswalk, Saturation flow decreases. On average, one unit increase in the violations by pedestrians at exit crosswalk (per hour) leads to saturation flow decreases by 0.955 unit.
- From study, it was found that as traffic light violation of vehicle's increases, saturation flow decreases. On average one unit increase in the traffic light violations by vehicles (per hour) leads to saturation flow decreases by 0.543 unit.
- From study, it was found that as lateral movement of vehicle's increases, saturation flow decreases. On average one unit increase in the vehicle's lateral movement leads to saturation flow decreases by 0.553 unit.
- The multiple regression model estimated the base saturation flow rate to be 5425.980 PCU/hr which is closer to value suggested by INDOHCM 2017.
- In regression model traffic composition variables such as percentage of 2W, 3W and car gives positive impact on saturation flow rate and percentage of bus, lcv and slow moving vehicle gives negative impact on saturation flow rate.
- Pedestrian phase should be added in traffic signal system in order to regulate the pedestrians safely at both the intersection considered in the study.
- Traffic rules for pedestrian movement at intersection should be enforced and they should be fined if not followed.

VIII. FUTURE SCOPE

- The regression model developed for saturation flow rate is based on traffic condition of Ahmedabad city, which is assumed to be similar to other parts of India. This developed model may be applied in other cities if India and checked for its usefulness.
- It is recommended to use greater number of observation cycles including greater number of intersections for model calibration.
- The estimated saturation flow rate of the intersection can be simulated in the VISSIM software for the validation.

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