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Estimating Base Saturation Flow Rate for Selected Signalized Intersections in Khartoum State, Sudan

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Abstract — The environmental characteristics of the roads and the behavior of the drivers are the most important performance factors of signalized intersections highway capacity manual provide factors that may not correspond to the nature of local traffic. To address this issue, The Ideal saturation flow rate was studied by analyzing the preliminary data and presenting these results to show the change between the capacity factor in the highway capacity manual and the local reality of Khartoum state and with the technical factors to develop traffic to reduce congestion and safety, there are several external factors such as the behavior of pedestrian movement; Drivers' behavior which is negatively affects the traffic performance, in development countries.

Results showed that the ideal capacity saturation flow rate in Khartoum is 1636 passenger cars per hour of green time per lane which is lower than the value mentioned in Highway Capacity Manual HCM. Moreover, the results and outputs can be used in signalized intersection design and traffic analysis in Sudan. In spite of the technical factors to develop traffic to reduce congestion and safety, there are several external factors such as pedestrian behavior and drivers' behavior negatively affects traffic performance and reduce the capacity. Traffic Awareness and Traffic Enforcement must be applied with the technical improvements to optimize the traffic performance in development countries.

Index Terms—Saturation flow rate, Base saturation flow rate, Signalized intersections Capacity, [1]

I. Introduction

At-grade intersection is one of the most critical elements that influence the performance of urban traffic network. For safe and efficient movement of large volumes of traffic, intersections are usually signalized. The design and operations of a signalized intersection rely critically on its capacity. The Highway Capacity Manual (Transportation Research Board, 2000), Canadian Capacity Guide (Telph, 1995) and the Australian Road Research Board's (ARRB) Special Report on Traffic Capacity and Timing Analysis (Akcelik, 1981) provide general guidelines concerning operational characteristics and estimating the capacity of a signalized intersection. Teply and Jones (1991) and Khosla (2006) summarize the concepts and compare the measurement techniques used by agencies and researchers in different countries. In general, the capacity of a signalized intersection relies on the Saturation Flow Rate (SFR) in ideal condition and adjustment factors to accommodate prevailing geometric and traffic conditions. Although manuals specify values for these parameters, researchers have observed significant fluctuation in these values among different locations due to variations in behavioral and environmental characteristics (Bester and Meyers, 2007; Bonneson *et al.*, 2005; Liu *et al*., 2005; Turner and Hatahap, 1993 and Zegeer 1986) [1].

Sudan has experienced rapid growth in traffic volume and various modes of transportation on the road network. With the limited capacity of the network, this has led to increasing traffic congestion and traffic jams can be observed on many roads and intersections in Khartoum City and for prolonged periods of time.

For the efficient design and operation of a road network in the city traffic flow parameters, including intersection capacity and corresponding adjustment factors, should be reassessed on the basis of local traffic characteristics. To predict the capacity of signalized intersections in Sudan, this research focuses on the determination of Ideal Saturation Flow Rate for urban roads in Khartoum State – Sudan by analyzing the saturation flow rate for approaches at signalized intersections in Khartoum. [2]

II. Review of the Literature

The Highway Capacity Manual (HCM) defines saturation flow rate as "the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that a green signal is available at all times and no lost time is experienced." [4] It suggests an ideal saturation flow rate of 1900 passenger cars per hour of green time per lane (pcphpl). Adjustment factors are applied to address the impacts of prevailing (local traffic) conditions that deviate from ideal conditions relating to roadway geometry (e.g. lane width, lateral clearance, number of lanes, grades), vehicle composition and proportion of turning movements (Highway Capacity Manual, 2000). [3]

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HCM recommends measurement of saturation flow rate for each lane based on observed headways as vehicles pass over the stop line of the intersection approach. It observes that for most cases the first four headways include lost time. For measuring saturation headway it proposes to commence with the fifth headway in the queue and end when the front wheels of the last vehicle in the standing queue crosses the stop line. The saturation flow rate is calculated as the reciprocal of the mean saturation headway. The discharge headway method is also widely used for estimating saturation flow rate at signalized intersections. Previous studies indicated that discharge headway would converge to saturation headway after the fourth to sixth discharged passenger car crossing the stop line since the beginning of the green light (Roess *et al*., 2004). [3]
The Research analyses the saturation flow rate at signalized intersection in Khartoum, Sudan to facilitate improved design and operational management.
Furthermore, movement are examined and headway are analyzed to predict the capacity of signalized intersections in the city.

III. Data Collection

To determine the saturation flow rate at signalized intersection, three signalized intersections in Khartoum, Sudan, Fig. 1 shows the location of the study sites. All data were recorded during peak hours on weekdays, during the period from March 2015 to May 2015, traffic operation at the study area has been recorded by using a video camera, volume and headway data were then transcribed manually using stop watch and headway form and S_0 factor has been calculated by Excel Spreadsheet for three periods 9 hours Morning, Afternoon and Evening time period 3 hours for each period.

Figure 1. Location of selected intersections

- INT#1 Gamaa Street & Meknemer Street Intersection
- INT#2 Meknemer Street & Gamhoria Street Intersection
- INT#3 Baladia Street & Mauna Street Intersection

For the study four leg intersections have been selected in Khartoum State – Sudan Figure 1. Show intersections locations in Khartoum State.

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Figure .2 Baladia & Mauna Intersection – Camera Location

The average cycle length of intersection is 122.5 seconds while the average green interval in major approaches of the different intersections is 35 seconds.

As vehicles in the queue begin crossing the reference line at a signalized intersection after the signal becomes green, the time elapsed between successive vehicles provides the corresponding discharge headway which determines the capacity and adjustment factors for different types of movements.

From video images headway information was transcribed in accordance with the HCM standard procedure (Highway Capacity Manual, 2000) [1].

Saturation headway was estimated from the average of the uniform headways which generally occurred after the fourth or fifth vehicle in the queue. For adjustment factors, headway data for each type of movement was transcribed and analyzed using the equations described below.

IV. Saturation Flow Rate Measurement

The basic saturation flow rate was measured for thru lanes during cycles containing only passenger cars and satisfying the criteria for ideal conditions. It was estimated on the basis of measured average headways using Equation (1) to calculate average headway [1]

Saturation Flow Rate in local conditions was found as 1636 pcphpl which is significantly lower than 1900 pcphpl suggested in HCM (Highway Capacity Manual, 2000). [1]

$$S = \frac{3,600}{h} \qquad 1$$

Where:

S =saturation flow rate, vehicles per hour of green per lane (veh/h/g/In)

h =saturation headway, seconds/vehicle (s/veh)

HCM 2000 uses a default base saturation flow rate of 1900 pc/h/ln, this value may be increased or decreased on the basis of local field measurements. Approaches with lower approach speeds (less than 50 km/h) often have lower base saturation flow rates, on the order of 1,800 pc/h/ln. Approaches with higher approach speeds (greater than 80 km/h) may have base saturation flow rates higher than 1,900 pc/h/ln. [1]

V. Saturation flow rate in Khartoum State, Sudan

The uses of Saturation flow rate 1900 pcphpl may affect the signal design, phasing and operation and will lead to poor traffic signal design. Table 1 Shows comparison between using default HCM factor 1900 pcphpl in signal design and Modified ideal saturation flow factor due city traffic environment

INT	Direction	EB	WB	NB	SB	All
Intersection #1	Volume (vph)	1298	315	1491	1532	4636

	Total Delay (hr) HCM Default S0 Factor	62	5	72	123	262
	Total Delay (hr) HCM Modified S0 Factor	87	6	109	197	399
Intersection #2	Volume (vph)	0	2119	1395	1001	4515
	Total Delay (hr) HCM Default S0 Factor	0	68	30	33	131
	Total Delay (hr) HCM Modified S0 Factor	0	60	100	83	243
Intersection #3	Volume (vph)	646	833	1012	652	3143
	Total Delay (hr) HCM Default S0 Factor	1	3	2	3	9
	Total Delay (hr) HCM Modified S0 Factor	1	5	2	3	11

Table.1 Total delay for HCM default factor and modified factor

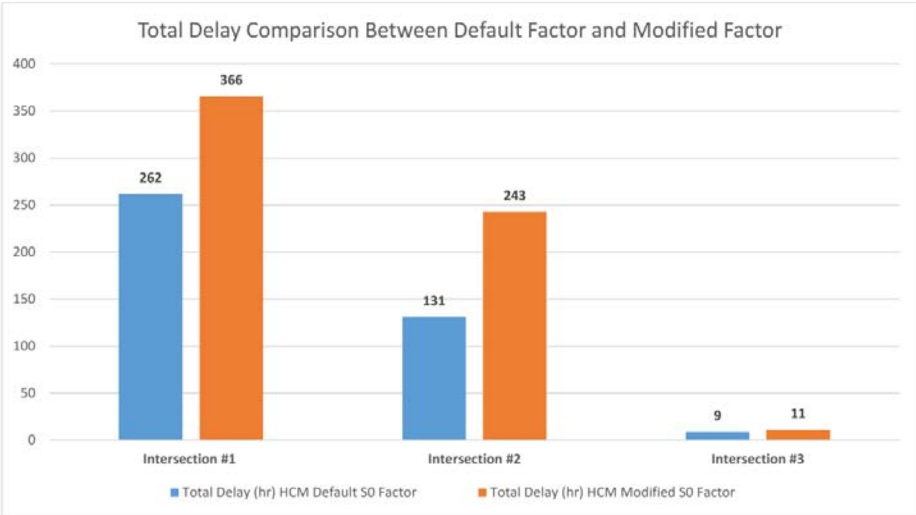

Figure.3 Total Delay Comparison between HCM default factor and modified factors

VI. Results

Average headway has been calculated from the video recordings for each cycle by calculating time of 4th Veh, (sec), Time of Last Stopped Veh (sec), Number of last stopped and end of green time (Sec). Eq. (2) was then used to compute the saturation headway. Table .2 summarizes the saturation headway statistics from the three intersections individually and combined. The headways ranged from 1.6 to 2.6 seconds. The differences are small between the three intersections. The mean of the headway for all intersections combined was 2.20 seconds, table. 2 show statistical summary for headway

	INT# 1	INT# 2	INT# 3	Combined
Mean	2.5	2.2	1.9	2.20
Median	2.5	2.2	1.9	2.20
Minimum	1.7	1.9	1.6	1.60
Maximum	2.6	2.4	2	2.60

Table.2 Statistical summary for headways

$$So= 3600 / 2.20 = 1636 \text{ pc/h/ln}$$

Analysis and results focuses primarily on the estimation of saturation flow rate and adjustment factors for signalized intersections in Khartoum. Results show that the ideal saturation flow rate in Khartoum is 1636 pcphpl. Although the value is about 13.8 percent lower than that recommended in the Highway Capacity Manual (2000), it is consistent with different observations in countries with neighboring countries, Saudi Arabia Makah reported a saturation flow rate 2500 pcphpl [3], Bester and Mayers (2007) reported a saturation flow rate of more than 2500 pcphpl in South Africa. [3]

Furthermore, studies on the Saturation flow rates to other countries showed that the HCM rates substantially underestimate roadway capacities applicable in those regions.

In Sudan many of traffic constrains and Obstacles led to the failure on traffic performance, and decrease the ideal saturation flow rate from the standards to lower level, these constrains are not found in neighboring countries and not considered in traffic analysis studies and these constrains are common in development countries such as:

- Pedestrians Behavior: In addition to the lack of a traffic signal for pedestrians, there is abnormal behavior of pedestrians crossing the road during the green time of the vehicles, and this poses a high risk to the safety of pedestrians, in addition to the drivers have to stop during the green time which allowed them to pass and to allow pedestrians to cross the road.(Figures 4,5,6)
- Drivers behavior, it is noticed that there is a strange behavior, the vehicle cross from the right hand side of the opposite direction during the red time and encounter with vehicles coming from the other direction. (Figure 7)
- Local environment, although the intersection of study in an urban area and represents the intersection of two main roads, but there is legal mode of transport not considered in Highway Capacity Manual HCM, as animal carts which effect the acceleration of vehicles and it is not compatible to be within traffic signal system. (Figures 8)

Figure. 4 Pedestrians crossing in med of intersection while green time to the opposite vehicle

Figure. 5 Pedestrians crossing and block the traffic while green time

Figure. 6 Pedestrians crossing Pedestrians crossing in med of intersection while green time to the opposite vehicle

Figure. 7 Drivers' behavior Driver Opposing directions on red time phase the vehicles in other direction.

Figure. 8 Animal Carts at signalized intersection with traffic stream.

Besides the general observation of varies modes of transportation and lack of road improvement, pedestrians random crossing, driving behavior, lack of traffic management for both of road and driver elements.
In Khartoum road network, as demonstrated low acceleration patterns due to external factors of drivers behaviors and local environment, lower values of saturation flow rate in Khartoum state, Sudan which influence to heavily congested situations because of using parameters not compatible with the local environment

VII. Conclusion and Recommendations

Based on analyses of saturation flow rate movements for signalized intersections in Khartoum, Sudan. The saturation flow rate for in Khartoum 1636 pcphpl which is significantly lower than the value recommended by the HCM (2000).
Capacity also falls sharply for a reduction in the number of lanes and lane width and lack of Traffic Management at both operational and strategic levels.
In spite of the technical factors to develop traffic to reduce congestion and safety, there are several external factors such as the behavior of pedestrian movement and Drivers' behavior negatively affects traffic performance, so Traffic Awareness and Traffic Enforcement must be applied with the technical improvements to optimize the traffic performance in development countries.
Results are expected to assist in signal design and formulation of a Highway Capacity Manual for Sudan. Findings of the study demonstrate that the design parameters of the traffic system may vary significantly depending on the local characteristics. For traffic safety and efficiency these parameters should be assessed using local data, and due to local environments.

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