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ESTIMATION OF BASE SATURATION FLOW RATES FOR SIGNALIZED INTERSECTIONS IN JORDAN AND KUWAIT

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ABSTRACT

The design and analysis procedures of signalized intersections depend on several factors including the base saturation flow rate. The Highway Capacity Manual (HCM) assumes a base saturation flow rate of 1900 passenger car/hour/lane (PCPHPL) for areas with population of more than or equal 250,000 and 1750 PCPHPL for areas with population of less than 250,000. This research aimed at determining the base saturation flow rate in Jordan and Kuwait based on field data collected from 60 signalized intersection approaches. The methodology was based on the direct field measurement of saturation flow rate and its main influencing factors. The HCM standard procedure was followed in the field data collection and results showed that the HCM base saturation flow rate value of 1900 PCPHPL is not suitable for Jordan and Kuwait. The study recommends a value of 2050 PCPHPL for Jordan and 2100 PCPHPL for Kuwait, while a value of 2075 PCPHPL may be used for other Middle Eastern countries that do not have field measured values. The saturation flow rate was found to be significantly affected by the speed limit, lane marking, city, and location (CBD/ Non-CBD) at 95 % confidence. On the other hand, the saturation flow rate was found not significantly affected by the number of lanes, time period, traffic volume, land use, area type, and development density at 95 % confidence.

Keywords: traffic signal, saturation flow rate, jordan, Kuwait.

INTRODUCTION

Signalized intersections are very common in Jordan and Kuwait and the majority are pre-timed. Many parameters are used in the design and analysis of signalized intersections including the saturation flow rate which is a very important parameter and all analysis procedures are sensitive to its value. According to the Highway Capacity Manual (HCM), Saturation flow rate is defined as the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced (TRB, 2010).

The HCM presented a model for estimating the saturation flow rate. This model includes a base value of saturation flow rate multiplied by adjustment factors.

The base saturation flow rate value introduced in the HCM is equal to 1900 PCPHPL for areas with population of more than or equal 250,000 and 1750 PCPHPL for areas with population of less than 250,000. The mentioned values were developed based on field measurements made in USA (TRB, 2010). Since different driver behaviors are expected in Jordan, Kuwait and other developing countries, the base saturation flow rate should be adjusted to represent the local conditions.

This research aimed at estimating the base saturation flow rate using data collected at signalized intersections from the two countries: Jordan and Kuwait. The methodology was based on the direct field measurement of saturation flow rate and its main influencing factors and statistical procedures were utilized to identify the significantly influencing factors. The HCM standard procedure was followed in the field data collection and the results were compared with the findings of other international studies and manuals including the HCM (TRB, 2010).

LITERATURE REVIEW

The base saturation flow rate represents the saturation flow rate value under ideal conditions, including lane width of 3.6 m, level terrain, no parked vehicles, no heavy vehicles, no pedestrians, and non-business area (TRB, 2010). The HCM suggests that, in the absence of the ideal conditions, the local base saturation flow rate can be calculated using the following formula:

$$S_{0,local} = 1900 \frac{\sum_{i=1}^{m} s_{prevailing}}{\sum_{i=1}^{m} s_{adjusted}} \tag{1}$$

Where:

$S_{0,local}$ = local base saturation flow rate for lane group I;

$S_{prevailing}$ = prevailing saturation flow rate for lane group I (measured from the field);

$S_{adjusted}$ = adjusted saturation flow rate for lane group I (computed using HCM formulas);

m = number of lane groups.

Many studies have investigated the saturation flow rate in different countries and showed significant variation from one country to another due to differences in the driver's behaviors and traffic conditions. In Beijing, Wan-chao *et al*. (Wan-chao *et al*, 2010) found that the saturation flow rate is affected by the number of through lanes. Keshuang and Hideki (Keshuang and Hideki, 2007) investigated the variability of saturation flow rate and showed that it tends to compress at small intersections. In Germany, saturation flow rate varied between 2080 and 2236 PCPHPL (Nielsen, 2011). Henk and Jie (Henk and Jie, 2010) found that the saturation flow rates in China are lower than those in the Netherlands by 20-30 %. Bin Alam *et al*. (2011) measured the base saturation flow rate in Makkah city in Saudi Arabia to be as high as 2500 PCPHPL.

Stanic (1994) found that the value of the base saturation flow rate which was estimated five decades ago has to be re-estimated based on local condition in each region. Edwin and Benekohal (2007) have found that the prevailing saturation flow rates in Panama City are greater than the adjusted saturation flow rates obtained using the HCM estimates. Similar results were also obtained in Malaysia by Vien *et al*. (2006) who found that the prevailing saturation flow rates differ significantly from the values computed using the HCM procedures. Joseph and Chang (2005) found that the saturation flow rates at signalized intersections in Maryland, USA varied between 1900 and 2200 vehicle/lane/hour. Bester and Myers (2007) noticed that the saturation flow rates in South Africa were much higher than those in the western countries and referred that to the aggressive behavior of the South African drivers. Mukwaya and Mwesige (2012) have found that using the same HCM base saturation flow rate value of 1900 vehicle/lane/hour in Uganda resulted in an overestimation of the capacity. Also, Hamad and Abuhamda (2015) have measured an average saturation headway of 1.55 seconds and a corresponding base saturation flow rate of 2,323 PCPHPL in Doha, Qatar.

DATA COLLECTION AND REDUCTION

A total of 60 intersection approaches were selected from Jordan (Amman, Zarqa and Irbid cities) and Kuwait to perform the study (Musa, 2014). The locations were selected to be as close as possible to ideal conditions by avoiding the usual causes of traffic interruption such as bus stops, pedestrian crossings, on street parking, etc. The selected approaches had low proportions of heavy vehicles (trucks and busses). Also, during the data collection, any cycle that included a truck and/or a bus was excluded from the data. Only straight movements were considered and shared lanes (through with left or right) were excluded from the data collection.

Field surveys for the selected locations were made during off peak periods to measure geometric elements (lane width, street width, number of lanes, etc.), area type, land use, speed limit, lane marking, and development density. Direct measurement using mobile application was used to collect traffic data from the selected locations during peak periods, including time of study, traffic volume and prevailing saturation flow rate.

The collected data included: speed limit, lane marking, city, and location in the city, number of lanes, time period, land use, area type, and development density. If the lanes were not marked, the lane width was calculated by dividing the total street width by the number of lanes according to their actual use by traffic.

The traffic volume was treated as an indicator variable with three categories; “low” when some cycles during data collection had less than 8 queued vehicles, “medium” when there were more than 8 queued vehicles with sufficient green time for all queued vehicles to cross the signal, and “high” when there were more than 8 queued vehicles without sufficient green time for all queued vehicles to cross the signal (some queued vehicles had to wait for the next cycle).

The time period was also an indicator variable with three categories; “morning” from 6:00 AM to 11:59 AM, “afternoon” from 12:00 PM to 3:00 PM or “evening” from 3:00 PM to 11:59 PM.

The following HCM equation was used for measuring the prevailing base saturation flow rate for the selected through movements:

$$S_i = \frac{3600}{\frac{t_{last} - t_{fourth}}{n-4}} \tag{2}$$

Where:

S_i = saturation flow rate for subject lane group for that cycle (PCPHPL).

t_{last} = time for the last vehicle (seconds).

t_{fourth} = time for the fourth vehicle (seconds).

n = number of vehicles in that cycle.

Tables 1 and 2 show the lists of the scalar and categorical variables used in this study.

Table-1. List of scalar variables.

Factor	Symbol	Unit
Prevailing saturation flow rate	S	PCPHPL
Street width	W_t	m
Lane width	W_l	m
Speed limit	SL	Km / hour

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Table-2. List of categorical variables.

Factor	Symbol	Meaning
Lane marking	M	Marked
	UM	Unmarked
Time period	M	Morning
	A	Afternoon
	E	Evening
Traffic volume level	H	High
	M	Medium
	L	Low
City	A	Amman
	I	Irbid
	Z	Zarqa
	K	Kuwait
Land Use	E	Educational
	R	Residential
	C	Commercial
	I	Industrial
Location	C	Central business district (CBD)
	NC	NON-CBD
Area Type	U	Urban
	SU	Suburban
Development density	H	High
	M	Medium
	L	Low

DATA ANALYSIS

This section includes the measured values of the base saturation flow rate and an analysis of the significance of the effect of each of the considered factors. The significance was tested by one-way ANOVA using the Statistical Package for the Social Sciences (SPSS) software.

Estimated Base Saturation Flow Rate

The HCM procedure (equation 1) was followed to compute the base saturation flow rate for each city, each country, and the two countries combined. As shown in Table-3, the highest base saturation flow rate (in PCPHPL) was estimated as 2097 for Kuwait followed by 2077 for Amman city, then 2052 for Irbid city with the lowest value of 1995 for Zarqa city. The country values (in PCPHPL) were 2046 for Jordan and 2073 for both Jordan and Kuwait combined. All calculated base saturation flow rate values were higher than the HCM default value of 1900 PCPHPL meaning that the HCM underestimates the actual base saturation flow rate for the two countries. This is in agreement with the results of studies in some other countries such as Germany with saturation flow rate of 2080 - 2236 PCPHPL (Nielsen, 2011), Maryland in USA with saturation flow rate of 1900 – 2200 PCPHPL (Joseph and Chang, 2005), Makkah city in Saudi Arabia with saturation flow rate of 2500 PCPHPL (Bin Alam *et al*, 2011), and Doha in Qatar with saturation flow rate of 2,323 PCPHPL (Hamad and Abuhamda, 2015).

Table-3. Estimated base saturation flow rates.

Location	Number of intersections	Base saturation flow rate (PCPHPL)
Amman	14	2076.83
Irbid	6	2052.35
Zarqa	9	1995.16
Jordan	29	2045.98
Kuwait	31	2096.82
Jordan and Kuwait	60	2072.86

Effect of Speed Limit

Based on ANOVA analysis, it was found that the measured saturation flow rate is significantly affected by the speed limit at 95 % confidence level (F-value =3.289, $p < 0.017$). The mean and standard deviation of the saturation flow rate for different speed limits are shown in Table-4.

Table-4. Effect of speed limit on saturation flow rate.

Speed Limit	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
45	15	1932.46	122.65
50	11	1828.24	112.99
60	6	2034.74	117.11
70	5	1924.29	150.29
80	23	1996.32	165.47
Total	60	1947.38	151.97

Effect of Number of Lanes

Based on ANOVA analysis, it was found that the measured saturation flow rates are not significantly affected by the number of lanes at 95 % confidence level (F-value = 0.893, $p < 0.451$). Mean and standard deviation of the saturation flow rate for different numbers of lanes are shown in Table-5.

Table-5. Effect of number of lanes on saturation flow rate.

Number of Lanes	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
2	6	1852.81	170.40
3	20	1962.09	162.47
4	28	1958.96	148.87
5	6	1938.90	105.18
Total	60	1947.38	151.97

Effect of Lane Marking

Based on ANOVA analysis, it was found that the measured saturation flow rate is significantly affected by street lane marking at 95 % confidence level (F-value =11.733, $p < 0.001$). The mean and standard deviation of the saturation flow rate for the effect of street lane marking are shown in Table-6, where higher saturation flow rates were measured when street lane marking was present.

Table-6. Effect of lane marking on saturation flow rate.

Lane Marking Presence	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
No	29	1883.47	151.15
Yes	31	2007.17	128.27
Total	60	1947.38	151.97

Effect of Period

Based on ANOVA analysis, it was found that the measured saturation flow rates are not significantly affected by the time of day at 95 % confidence level (F-value =0.315, $p < 0.731$). Mean and standard deviation of the saturation flow rate for different times of the day are shown in Table-7.

Table-7. Effect of time period on saturation flow rate.

Time of Day	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
Morning	15	1974.69	155.32
Afternoon	12	1938.21	143.77
Evening	33	1938.30	156.38
Total	60	1947.38	151.97

Effect of Traffic Volume

Based on ANOVA analysis, it was found that the measured saturation flow rates are not significantly affected by the traffic volume level at 95 % confidence level (F-value =1.038, $p < 0.361$). Mean and standard deviation of the saturation flow rate for different traffic volumes are shown in Table-8.

Table-8. Effect of traffic volume on saturation flow rate.

Traffic Volume	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
High	14	1975.30	164.32
Medium	29	1953.19	167.73
Low	17	1903.55	114.02
Total	60	1944.29	153.53

Effect of City

Based on ANOVA analysis, it was found that the measured saturation flow rate is significantly affected by the city at 95 % confidence level (F-value =7. 294, $p < 0.000$). The mean and standard deviation of the saturation flow rate for different cities are shown in Table-9. The highest saturation flow rate (in PCPHPL) was measured as 2016 for Kuwait city followed by 1914 for Amman city, then 1880 for Zarqa city with the lowest value of 1773 for Irbid city.

Table-9. Effect of city on saturation flow rate.

City	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
Amman	14	1914.24	147.43
Irbid	6	1773.23	114.88
Zarqa	9	1879.88	131.75
Kuwait	31	2015.65	128.10
Total	60	1947.38	151.97

Effect of Location in the City

Based on ANOVA analysis, it was found that the measured saturation flow rate is significantly affected by the location in the city (CBD or Non-CBD) at 95 % confidence level (F-value =4.056, $p < 0.049$). The mean and standard deviation of the saturation flow rate for the location in the city are shown in Table-10, where higher saturation flow rates were measured at the Non-CBD intersections.

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Table-10. Effect of location in the city on saturation flow rate.

Location in the City	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
Non-CBD	32	1983.42	140.63
CBD	28	1906.19	156.40
Total	60	1947.38	151.97

Effect of Land Use

Based on ANOVA analysis, it was found that the measured saturation flow rate is not significantly affected by land use type (educational, commercial, residential, and industrial) at 95 % confidence levels (F-value =1.092, p < 0.360). The mean and standard deviation of the saturation flow rate for different cities are shown in Table-11. The highest saturation flow rate was measured at educational land use and the lowest was measured at commercial land use.

Table-11. Effect of land use on saturation flow rate.

Land use	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
Educational	9	1982.16	182.20
Residential	19	1979.64	124.51
Commercial	25	1905.94	158.04
Industrial	7	1963.09	154.45
Total	60	1947.38	151.97

Effect of Area Type

Based on ANOVA analysis, it was found that the measured saturation flow rate is not significantly affected by area type (urban and sub urban) at 95 % confidence level (F-value =2.653, p < 0.109). Mean and standard deviation of the saturation flow rate for different area types are shown in Table-12, where higher saturation flow rates were measured at suburban intersections.

Table-12. Effect of area type on saturation flow rate.

Area Type	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
Suburban	16	1999.65	173.25
Urban	44	1928.37	140.82
Total	60	1947.38	151.97

Effect of Development Density

Based on ANOVA analysis, it was found that the measured saturation flow rate is not significantly affected by the development density (low, medium, and high) at 95 % confidence level (F-value =0. 073, p < 0.930). Mean and standard deviation of the saturation flow rate for different development densities are shown in Table-13.

Table-13. Effect of development density on saturation flow rate.

Development Density	N	Saturation flow rate (PCPHPL)	
		Mean	Std. Deviation
High	27	1944.98	165.65
Medium	21	1956.77	146.12
Low	12	1936.34	141.00
Total	60	1947.38	151.97

Table-14 shows a summary of the results where the effect on the saturation flow rate was significant by four factors (speed limit, lane marking, city, and location in the city) and not significant by six factors (number of lanes, time period, traffic volume, land use, area type, and development density) at 95 % confidence.

Table-14. Summary of significance for all factors.

Variable	F-value	P	Significance at 95 % confidence
Speed limit	3.289	0.017	Significant
Number of lanes	0.893	0.451	Not significant
Lane marking	11.733	0.001	Significant
Time period	0.315	0.731	Not significant
Traffic volume	1.038	0.361	Not significant
City	7.294	0.000	Significant
Location	4.056	0.049	Significant
Land use	1.092	0.360	Not significant
Area type	2.653	0.109	Not significant
Development density	0.073	0.930	Not significant

CONCLUSIONS

Based on the results of this study, it can be concluded that:

a) The HCM base saturation flow rate value of 1900 PCPHPL is not suitable for Jordan and Kuwait. A value of 2050 PCPHPL is recommended for Jordan, and a value of 2100 VPHPL is recommended for Kuwait. A value of 2075 VPHPL may be used for other Middle Eastern where no field measurements are present.
b) The estimated base saturation flow rate values in this study were all higher than the HCM default value which is in agreement with the results of studies in some other countries such as Germany with saturation flow rate of 2080 - 2236 PCPHPL, Maryland in USA with saturation flow rate of 1900 – 2200 PCPHPL,

Makkah city in Saudi Arabia with saturation flow rate of 2500 PCPHPL, and Doha in Qatar with saturation flow rate of 2,323 PCPHPL.

c) The saturation flow rate is significantly affected by the speed limit, lane marking, city, and location at 95 % confidence.
d) The saturation flow rate is not significantly affected by the number of lanes, time period, traffic volume, land use, area type, and development density at 95 % confidence.

Further research is recommended to cover more countries to have more representative international results.

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