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OPERATIONAL ANALYSIS OF ISOLATED SIGNALIZED INTERSECTIONS USING THREE TRAFFIC SOFTWARES

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Abstract: *The operation analysis of isolated signalized intersection provides valuable and important information about the performance of transportation system in the city. The signalized intersections are major elements and critical points within the city transportation network; therefore accurate detailed information and data about the capacity and operation performance of the signalized intersections is very important and more significant to evaluate and improve the capacity of the transportation system and network of the city. Highway Capacity Manual (HCM) Model is widely used for operation analysis of the isolated signalized intersections in Iraq through number of traffic analysis software tools which uses the HCM delay model. The most popular and widely used among traffic analysis software tools are; HCS 2010, SIDRA 5.1 and TRANSYT-7F Release 11. The objective of this study is a comparison between these three traffic analysis software tools based on evaluation of the quality of their operation analysis and optimization capabilities of isolated signalized intersections in order to be a good guide for the traffic engineers to decide which of these tools provide better results in evaluating the quality of isolated signalized intersections operation performance and optimizing intersection parameters. To achieve this objective, Bukhari signalized intersection in Kalar City was selected and the required data for the study purposes were collected. Based on results of this study SIDRA 5.1 is the most effective and the richest operation analysis and optimization software among the three selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11.*

Keywords: Signalized intersection, Operation analysis, Optimization, HCS 2010, SIDRA 5.1, TRANSYT-7F

1. INTRODUCTION

Traffic software tools are widely used in operation analysis of the isolated signalized intersections in Iraq through number of traffic analysis softwares which uses the HCM delay model. The most popular and widely used among traffic analysis software tools are; HCS 2010, SIDRA 5.1 and TRANSYT-7F. A comparison between these three traffic analysis software tools based on evaluation of the quality of their operation analysis and optimization capabilities of isolated signalized intersections can be a good guide for the traffic engineers to decide which of these tools provide better results in evaluating the quality of isolated signalized intersections operation performance and optimizing intersection parameters.

Some major and basic information about the three software tools; HCS 2010, SIDRA 5.1 and TRANSYT-7F are summarized in Table 1 (McTrans 2008; McTrans 2012; SIDRA SOLUTIONS 2012).

Table 1. Major and basic information about the three software tools; HCS 2010, SIDRA 5.1 and TRANSYT-7F

Traffic Software Tool	Developed By	Traffic Software Tool Function (Related to Signalized Intersection)	Simulation Run Output Results	Optimization Run Output Results	References
HCS 2010	McTrans Center, University of Florida	Signalized intersection capacity and LOS. The analysis\Isolated signalized intersection\up to 4 approaches for each intersection.	Its simulation run outputs includes; degree of saturation, uniform delay, incremental delay, control delay, intersection delay and LOS	Its optimization run output results include; optimized cycle length, degree of saturation, uniform delay, incremental delay, control delay, intersection delay and LOS	(McTrans 2012)
SIDRA 5.1	Akcelik & Associates Pty Ltd, Australia	Tool for isolated intersection performance and timing analysis \Isolated signalized intersections\up to 8 approaches for each intersection.	Its simulation run output results include very important measures of effectives such as; degree of saturation, total and average delay, LOS, performance index (disutility index), fuel consumption, emissions, and operating costs	Its optimization run output results include; optimized cycle length, degree of saturation , total and average delay, LOS, performance index (disutility index), fuel consumption, emissions, and operating costs	(SIDRA SOLUTIONS 2012)
TRANSYT-7F Release 11	McTrans Center, University of Florida	Is a traffic simulation and signal timing optimization program\from 1 to 99 signalized intersection (work from the range of one intersection as isolated signalized intersection and up to 99 signalized intersections as a network)\ up to 4 approaches for each intersection.	Its simulation run output results include very important measures of effectives but with less range of outputs than SIDRA 5.1, the outputs include; degree of saturation, uniform delay, random delay, total delay, average delay, LOS, performance index (disutility index) and fuel consumption.	Its optimization run output results include; optimized cycle length, control delay, fuel consumption and performance index (disutility index)	(McTrans 2008)

To estimate delay time at two important intersections at Palestine Street in Baghdad City the Capital of Iraq, the two traffic software tools; Highway Capacity Software (HCS) and the Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) Software were used. The analysis results of the two softwares; HCS and SIDRA showed that, the HCS gives different delay time values than SIDRA by a small percent and the SIDRA model can be improved significantly and used for traffic analysis in Baghdad conditions by calibrating the basic saturation flow rate (Jameel 2011).

A research carried out in Jordan to check out the validation of the two traffic software tools; the Highway Capacity Software (HCS) and the Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) Software which are widely used for estimating delay at signalized intersections in Jordan. The analysis results of the two softwares; HCS and SIDRA showed that, for low delay ranges, HCS tends to slightly over-estimate control delay; while SIDRA has a predicted control delay that is in good agreement

with the field data. At higher delay levels, HCS has noticeable scattered predictions as compared to field data with more tendencies to over-estimation, while SIDRA provides less scattering than HCS. However, SIDRA showed a better performance than HCS (Al-Omari, B., Ta'amneh 2007).

The analysis results of comparison study between the three traffic software tools; TRANSYT-7F, Synchro and HCS based on signalized intersection delay estimation for 8 signalized intersections in Seattle, Washington, United States showed that, each program has its strengths and weaknesses, and neither is ideal for every situation. The analyst should carefully consider how each program's characteristics mesh with the study-section characteristics and project objectives when making a decision as to which program to use for a particular study (Washburn, S., Larson, N. 2002).

This study compares three traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 based on the evaluation of the quality of their operation analysis and optimization capabilities of isolated signalized intersections. Evaluation includes testing how well these traffic analysis software tools estimate or predict signalized intersections; degree of saturation, delays, queue lengths, queue spillback, fuel consumption, disutility index, levels of service, and optimization capabilities.

2. HCM2000 AND HCM2010 EDITIONS SIGNALIZED INTERSECTIONS CONTROL DELAY MODELS

HCM Model is widely used for operation analysis of the signalized intersections in Iraq and worldwide through number of traffic analysis software tools which uses the HCM delay model. Among the most popular and widely used among traffic analysis software tools are; HCS 2010, SIDRA 5.1 and TRANSYT-7F Release 11.

McTrans as part of its software maintenance developed and maintained the Highway Capacity Software (HCS) as a faithful implementation of the HCM procedures. Since its first issue to McTrans, additional extensive versions to the computational code are made. The HCM 2010 is the basis for the LOS and capacity computation included in HCS (McTrans 2012).

SIDRA 5.1 was released in March 2011, in coincided with the release of Highway Capacity Manual 2010. It included the Highway Capacity manual 2010 LOS methods, delay models and default parameters were adopted. SIDRA 5.1 included large enhancements to traffic models, user interface and program features (SIDRA SOLUTIONS 2012).

TRANSYT 7F uses the HCM 2000 delay model, but also uses macroscopic simulation results to allow HCM 2000 delay model to recognize complex traffic operations (McTrans 2008).

3. STUDY AREA

Kalar City is the center of Kalar District located in the northeast of Iraq and northeast of Capital of Iraq Baghdad with 220 Km approximate distance, and it is one of Sulaimaniya Governorate Districts and lies on Sirwan (Diyala) river. Currently Kalar city is the center of Garmian Area Administration, the population of Kalar City is (197,230 persons) which represent (74%) of Kalar District population according to information collected by Garmian Directorate of Statistics.

Kalar now is in a continuous progression toward further urban expansion and infrastructural growth due to its location which connects Iraq, Iran and Kurdistan together. The rapid and big increase of Kalar City population is the major cause of the increasing demand for suitable and adequate transportation system and traffic network in terms of capacity and mobility to avoid the major operation problems especially during the peak periods.

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4. CASE STUDY

As a case study a major congested signalized intersection (Bukhari intersection) has been selected. Bukhari signalized intersection has congested traffic and represents significant traffic facility in Kalar City traffic system because it's important location, where it is located next to the Presidency of University of Garmian and connect Kalar-Kefri Districts multi lane two-way highway with the center of Kalar city (see Figures 1 and 2).

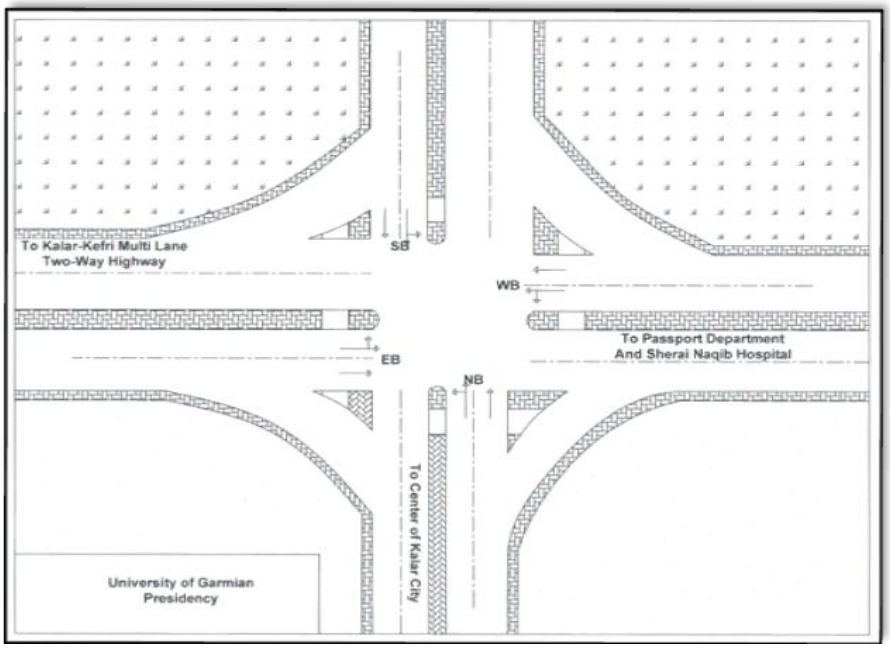

Figure 1. Bukhari signalized intersection existing geometric design

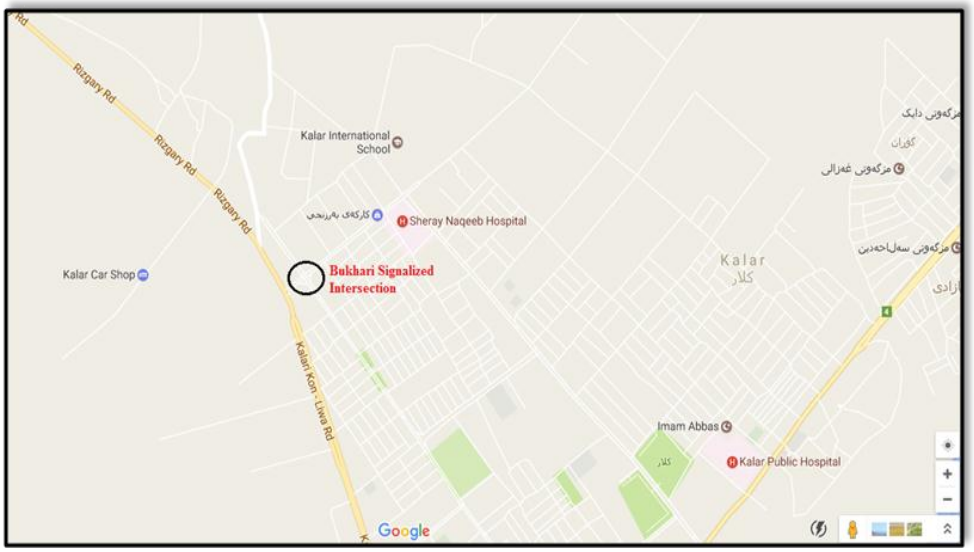

Figure 2. Map of Kalar City locating Bukhari signalized intersection (Google Maps)

5. DATA COLLECTION

In order to evaluate the operation performance of the selected isolated signalized intersection (Bukhari intersection) using; traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 field observation including traffic volumes, geometric data and other required data should be collected. The data collection is done manually and using video records on working days during the highest congestion of the transportation system at peak hours.

5.1. TRAFFIC VOLUME

Traffic volume count carried out at Bukhari intersection during the peak period (the peak period is selected based on the personal observation and information from the Garmian Traffic Police Directorate) from (8:25 a.m to 9:25 a.m) using video record (see Figure 3) during the working day on 17th of July 2016.

The highest traffic volume in each direction is recorded to be used in the analysis of the present study.

Figure 3. Bukhari intersection signalized intersection-traffic volume count using video record

The traffic volume counting period is divided into 15 minutes intervals; Table 2 shows the total volume for all approaches in Bukhari signalized intersection.

6. RESULTS AND DISSCUSION

The rules for editing the document briefly describe the characteristics of form elements of the document content Operation analysis (simulation runs) and optimization of Bukhari isolated signalized intersection using; traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11:

6.1. OPERATION ANALYSIS (SIMULATION RUNS) OF BUKHARI SIGNALIZED NTERSECTION USING; HCS 2010, SIDRA 5.1 AND TRANSYT-7F RELEASE 11 SOFTWARE TOOLS

For the Evaluation purposes of the selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 which are currently widely used in Iraq in term of their results of isolated signalized intersections operation analysis. A simulation runs applied on Bukhari isolated signalized

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intersection using the selected three softwares and the major output results of the three simulation runs of the three selected softwares are summarized in Tables 3, 4 and 5

Table 2. Traffic Volume, Peak Hour Factor (PHF), Phases Sequence and Signal Timing at Bukhari Signalized Intersection for all Approaches in the Peak Hour Period

Collected Data		NB		SB		EB		WB	
		TH	LT	TH	LT	TH	LT	TH	LT
Movement No.		101	102	103	104	105	106	107	108
Traffic volume	8:25-8:40 a.m (15 min.)	16	52	37	17	71	4	180	96
	8:40-8:55 a.m (15 min.)	26	48	38	8	120	4	89	60
	8:55-9:10 a.m (15 min.)	19	51	29	10	91	1	116	84
	9:10-9:25 a.m (15 min.)	14	63	17	4	110	6	95	49
	8:25-9:25 a.m (1 hour)	75	214	121	39	392	15	480	289
HV		0	6	1	0	24	0	50	8
HV%		0	3	1	0	6	0	10	3
PHF		0.72	0.85	0.80	0.57	0.82	0.63	0.67	0.75
Signal Timing (sec)		G=20 Y=5 All Red=2		G=25 Y=5 All Red=2		G=25 Y=5 All Red=2		G=30 Y=5 All Red=2	
Phases Sequence									

TH= Through movement, LT= Left movement, and
% HV=Percent of Heavy Vehicles

Table 3. Operation analysis (a simulation run) major output results for Bukhari signalized intersection using HCS 2010

Operation Analysis Outputs	Eastbound	Westbound	Northbound	Southbound
	LT	LT	LT	LT
Lane Group Degree of Saturation	92	170	44	33
Lane Group Uniform Delay (sec)	53.2	51.5	41.9	44.3
Lane Group Incremental Delay (sec)	23.6	323.6	1.8	1.3
Lane Group Control Delay (sec)	76.8	375.1	43.7	45.6
Lane Group LOS	E	F	D	D
Approach Control Delay (sec)	76.8	375.1	43.7	45.6
Approach LOS	E	F	D	D
Intersection Delay (sec/veh)	219			
Intersection LOS	F			

Bukhari signalized intersection operation analysis major outputs resulted from the simulation runs of the selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 show that:

- SIDRA 5.1 is the richest operation analysis software to measure the effectiveness of isolated signalized intersections. Its simulation run output results include very important measures of effectives such as degree of saturation, total and average delay, LOS, performance index (disutility index), fuel consumption, emissions, and operating costs (see Table 4).
- TRANSYT-7F is providing similar to SIDRA 5.1 valuable and significant simulation run output results but less wide range, where Its simulation run output results include very important measures of effectives such as degree of saturation, uniform delay, random delay, total delay, average delay, LOS, performance index (disutility index) and fuel consumption (see Table 5).
- HCS 2010 provides operation analysis output results include some major and important measures of effectiveness (MOE) without calculating or referring to other measures of effectiveness such as fuel consumption, performance index, emissions and operating costs. Its simulation run output results include degree of saturation, uniform delay, incremental delay, control delay, intersection delay and LOS (see Table 3).

6.2. OPTIMIZATION OF BUKHARI SIGNALIZED INTERSECTION USING; HCS 2010, SIDRA 5.1 AND TRANSYT-7F RELEASE 11 SOFTWARE TOOLS

For the comparison and evaluation purposes of the selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 in term of their results of optimizing isolated signalized intersections signal timing. An optimization runs applied on Bukhari isolated signalized intersection using the selected three softwares and the major output results of the three optimization runs of the three selected softwares are summarized in Tables 6, 7 and 8.

Bukhari signalized intersection optimization major outputs resulted from the simulation runs of the selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 show that:

- The three selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11 have optimization capabilities.
- SIDRA 5.1 is very effective and the richest software to optimize isolated signalized intersections. Its optimization of signalized intersection cycle time produce very significant improvement on the intersection measures of effectiveness. Its output results include very important improved measures of effectives such as optimized cycle length, degree of saturation , total and average delay, LOS, performance index (disutility index), fuel consumption, emissions, and operating costs (see Tables 4 and 7).
- TRANSYT-7F is very capable and effective software to optimize isolated signalized intersections. Its optimization of signalized intersection cycle time produce very high percentage of improvement in the intersection measures of effectiveness. Its output results include optimized cycle length, control delay, fuel consumption and performance index (disutility index) (see Table 8). The optimization output results are much summarized and not reflect the optimization capabilities of TRANSYT-7F, therefore a simulation run applied using optimized cycle and phase's times to measure the improvement in the measures of the effectiveness for Bukhari signalized intersection. The simulation run using optimized cycle and phase's times major results include degree of saturation, uniform delay, random delay, total delay, average delay, LOS, performance index (disutility index) and fuel consumption which clearly explain the very big improvement in the measures of effectiveness of Bukhari signalized intersection (see Tables 5 and 9).

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Table 4. Operation analysis (a simulation run) major output results for Bukhari signalized intersection using SIDRA 5.1

Operation Analysis Outputs	Eastbound		Westbound		Northbound		Southbound	
	LT	TH	LT	TH	LT	TH	LT	TH
Degree of Saturation (%)	71.8	71.8	144.4	144.4	73.3	28.1	29.1	29.1
Average Delay (sec)	60.8	60.8	264.5	264.6	62	46.5	45.9	45.9
LOS	E	E	F	F	E	D	D	D
Approach Degree of Saturation (%)	71.8		144.4		73.3		29.1	
Approach Average Delay (sec)	60.8		264.5		57.4		45.9	
Approach Level of Service (LOS)	E		F		E		D	
Intersection Degree of Saturation (%)	144.4							
Intersection Total Control Delay (veh-h/h)	97.91							
Intersection Average Control Delay (sec)	161.7							
Intersection Worst Lane Control Delay (sec)	264.6							
Intersection Worst Movement Control Delay (sec)	264.6							
Intersection Geometric Average Delay (sec)	3							
Intersection Stop-Line Average Delay (sec)	161.7							
Intersection Level of Service (LOS)	F							
Performance Index (Disutility Index)	260.5							
Total Cost ($/hr)	1935.15							
Total Fuel Consumption (L/hr)	340.2							
Total Carbon Dioxide (kg/hr)	852.8							
Total Hydrocarbons (kg/hr)	1.609							
Total Carbon Monoxide (kg/hr)	54.08							
Total NOx (kg/hr)	1.62							

- HCS 2010 provides very simple and basic optimization output results with good improvement in reducing the intersection delay and enhance the intersection LOS. The optimization results include some major and important measures of effectiveness (MOE) without calculating or referring to other measures of effectiveness such as fuel consumption, performance index, emissions and operating costs. Its optimization run output results include degree of saturation, uniform delay, incremental delay, control delay, intersection delay and LOS (see Table 6).

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Table 5. Operation analysis (a simulation run) major output results for Bukhari signalized intersection using TRANSYT-7F Release 11

Operation Analysis Outputs	Eastbound		Westbound		Northbound		Southbound	
	LT*	TH	LT*	TH	LT*	TH	LT*	TH
Degree of Saturation (%)		98		191	60	26		36
Uniform Delay (veh-h)		7.5		42.8	3	1.1		2.7
Random Delay (veh-h)		4.9		127.1	0.4	0		0.1
Total Delay (veh-h)		12.4		170	3.4	1.2		2.8
Average Delay (veh-h)		89		555	49	41		46
Fuel Consumption (Liter)		73		558	27	10		23
Level of Service (LOS)		F		F	D	D		D
Intersection Degree of Saturation (%)	191							
Intersection Uniform Delay (veh-h)	57.2							
Intersection Random Delay (veh-h)	132.6							
Intersection Total Delay (veh-h)	189.9							
Intersection Average Delay (veh-h)	313							
Intersection Fuel Consumption (Liter)	693							
Intersection Performance index (Disutility Index)	178							
Intersection Level of Service (LOS)	F							

LT*: The left movement is shared with the through movement

Table 6. Signal timing optimization major output results for Bukhari signalized intersection using HCS 2010

Optimization Outputs	Eastbound	Westbound	Northbound	Southbound
	LT	LT	LT	LT
Lane Group Degree of Saturation (%)	91	87	95	94
Lane Group Uniform Delay (sec)	41.3	28.4	44.3	46.4
Lane Group Incremental Delay (sec)	21	8.1	36.4	45.2
Lane Group Control Delay (sec)	62.3	36.6	80.7	91.6
Lane Group LOS	E	D	F	F
Approach Control Delay (sec)	62.3	36.6	80.7	91.6
Approach LOS	E	D	F	F
Optimum Cycle Length (sec)	100			
Intersection Delay (sec/veh)	55.2			
Intersection LOS	E			

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Table 7. Signal timing optimization major output results for Bukhari signalized intersection using SIDRA 5.1

Optimization Outputs	Eastbound		Westbound		Northbound		Southbound	
	LT	TH	LT	TH	LT	TH	LT	TH
Degree of Saturation (%)	86.1	86.1	85.5	85.5	84.6	32.4	37.9	37.9
Average Delay (sec)	92.6	92.6	61.2	61.3	89.5	61.9	65.1	65
LOS	F	F	E	E	F	E	E	E
Approach Degree of Saturation (%)	86.1		85.5		84.6		37.9	
Approach Average Delay (sec)	92.6		61.3		81.4		65	
Approach LOS	F		E		F		E	
Optimum Cycle Length (sec)	160							
Intersection Degree of Saturation (%)	86.1							
Intersection Total Control Delay (veh-h/h)	43.69							
Intersection Average Control Delay (sec)	72.2							
Intersection Worst Lane Control Delay (sec)	92.6							
Intersection Worst Movement Control Delay (sec)	92.6							
Intersection Geometric Average Delay (sec)	3							
Intersection Stop-Line Average Delay (sec)	72.2							
Intersection LOS	E							
Performance Index (Disutility Index)	186.4							
Total Cost ($/hr)	1167.8							
Total Fuel Consumption (L/hr)	249							
Total Carbon Dioxide (kg/hr)	624							
Total Hydrocarbons (kg/hr)	1.095							
Total Carbon Monoxide (kg/hr)	44.49							
Total NOx (kg/hr)	1.365							

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Table 8. Signal timing optimization major output results for Bukhari signalized intersection using TRANSYT-7F Release 11

Optimization Results	Eastbound	Westbound	Northbound	Southbound
Initial signal timing (sec)	Green=20	Green=25	Green=30	Green=25
Optimized signal timing (sec)	Green=27	Green=46	Green=21	Green=8
Initial cycle length (sec)	128			
Optimized cycle length (sec)	130			
Initial control delay (sec/veh)	314			
Optimized control delay (sec/veh)	86.9			
Initial fuel consumption (lit/hr)	694			
Optimized fuel consumption (lit/hr)	314			
Initial Performance index (Disutility Index)	178.8			
Optimized Performance index (Disutility	71.12			

Table 9. Operation analysis (a simulation run using optimized cycle length) major output results for Bukhari signalized intersection using TRANSYT-7F Release 11

Operation Analysis (Optimized Cycle Time) Outputs	Eastbound		Westbound		Northbound		Southbound	
	LT*	TH	LT*	TH	LT*	TH	LT*	TH
Degree of Saturation (%)		74		105	87	38		113
Uniform Delay (veh-h)		6.7		13.6	3.7	1.4		4.3
Random Delay (veh-h)		0.9		13.2	1.9	0.1		6.4
Total Delay (veh-h)		7.7		26.8	5.6	1.5		10.7
Average Delay (veh-h)		55		87	80	52		177
Fuel Consumption (Liter)		58		161	34	11		47
LOS		E		F	F	D		F
Intersection Degree of Saturation (%)	113							
Intersection Uniform Delay (veh-h)	29.8							
Intersection Random Delay (veh-h)	22.6							
Intersection Total Delay (veh-h)	52.5							
Average Delay (veh-h)	86							
Fuel Consumption (Liter)	314							
Performance index (Disutility Index)	71							
Intersection Level of Service (LOS)	F							

LT*: The left movement is shared with the through movement

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7. CONCLUSIONS

1. Based on a comparison between the operation analysis results (simulation runs) of selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11. SIDRA 5.1 is the most effective and the richest operation analysis software among the three selected softwares, because of its wide range of output results which included; degree of saturation, total and average delay, LOS, performance index (disutility index), fuel consumption, emissions, and operating costs.

2. Based on a comparison between the optimization capabilities and optimization run results of selected computer traffic analysis software tools; HCS2010, SIDRA 5.1 and TRANSYT-7F Release 11. SIDRA 5.1 is the most effective and the richest optimization software among the three selected softwares, because of its large reduction of intersection delay and improving the intersection LOS, in addition to its wide range of output results which included; degree of saturation, total and average delay, LOS, performance index (disutility index), fuel consumption, emissions, and operating costs.

3. TRANSYT-7F Release 11 is very reliable and capable software in term of making a significant improvement in the measures of the effectiveness for the signalized intersections through the optimization of intersection cycle and phase's times.

4. HCS2010 is simple and easy software for operation analysis and signal time optimization of signalized intersection especially that is targeting the evaluation of intersection delay and level of service (LOS) and improving them, because of its significant reduction of intersection delay and improving the intersection LOS, but with limited range of output results which not including performance index (disutility index), fuel consumption, emissions, and operating costs.

RECOMMENDATIONS

Based on the results of this research it is highly recommended that Iraqi traffic engineers to select SIDRA 5.1 for operation analysis and optimization of signal timing of signalized intersections as it is the most effective and the richest operation analysis and optimization software among the three selected study softwares.

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