Synchro Software-Based Alternatives for Improving Traffic Operations at Signalized Intersections

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***Abstract—Traffic* congestion is a considerable problem in urban arterials, especially at signalized intersections. Signalized intersections are critical elements of the highway system, thus improving their performance would significantly influence the overall operating performance of the system in terms of delay and level of service (LOS). The aim of this study is to assess the capacity performance of two signalized intersections in Duhok city, namely, Zari land intersection and Salahaddin Mosque intersection using the procedure in the Highway Capacity Manual and Synchro software. Total intersection delay, LOS, and volume to capacity ratio (v/c) were the measures of effectiveness used for comparison purposes. Different optimization alternatives have been tested to improve current and future performance. The results have shown that the Zari land intersection is currently operating at LOS F with an average delay of 590 s/veh and high values of v/c at specific movements. Results of optimization show that the scenario of creating an overpass with a change in cycle length and adding one additional lane in each direction is the best alternative to improve its performance to the LOS D with the maximum v/c ratio of 0.86. For Salahaddin Mosque intersection, the delay can be reduced from 544 s/veh (LOS F) with high values of v/c at the major street through movement to an average delay of 70 s/veh (LOS E) and maximum v/c ratio of 1, when cycle length and geometrics are changed, and approaching traffic from the minor street is prohibited.**

***Index Terms*—Level of service, Optimization, Signalized intersections, Synchro software.**

I. Introduction

Signalized intersections are critical elements of highway system, thus improving the performance of these intersections significantly influences the overall operating performance of the highways, as the comfort of drivers and passengers is affected by the operational conditions of signalized intersections. An important parameter in explaining the operational conditions of signalized intersections is the concept of level of service (LOS) through measuring the control delay (HCM, 2010). Delay at signalized intersections is the time lost due to prevailing conditions including geometric characteristics, traffic, and control conditions present at the intersections.

Reduction in capacity and increase in delay at signalized intersections could be a reflection of poor signal timing as well as inadequate road geometry variables (Chen, Qi and Sun, 2014; Potts, et al., 2007). Efficient movement for pedestrians and orderly, maximizing the volume movement through an intersection, and increasing the capacity are depending on the properly designed and timed traffic signals (Koonce, et al., 2008). One of the effective methods to reduce delay at signalized intersections is improving the flow of traffic. Therefore, the alternatives of developing the optimal signal timing and improving geometrics using optimization software can make an efficient impact to reduce delay and improve the LOS at these intersections (He, et al., 2013; Roy, Barua and Das, 2015; Zhang, Sun and Kondyli, 2017). These problems can have a negative effect on drivers' comfort and LOS if not solved and optimized.

The literature covers a wide variety of researches indicating that one of the effective methods to reduce traffic congestion and delay and improving the performance of signalized intersections is the optimization of signal timing (Sunkari, 2004; Siddiqui, 2015; Udomsilp, et al., 2017; Ratrout and Assi, 2019). Others found that appropriate intersection improvement alternatives to achieve efficient operations include changing traffic signal timing, introducing additional lanes, and modifying the geometric conditions (Nyantakyi, et al., 2013; Roy, Barua and Das, 2015; Al-Allaff, et al., 2015; Zhang, Sun and Kondyli, 2017; Ragab and Abo El-Naga, 2019). Although, the focus of this research is using Synchro software and highway capacity manual (HCM) 2010 calculations, the findings from past published studies related to the evaluation and optimization of traffic performance at signalized intersections involved using different optimization software. Zhang, Sun and Kondyli (2017) used VISSIM software package to evaluate different optimization solutions and find a suitable alternative with the best performance measure or control delay. Based on the data of a representative intersection in Shanghai/China, introducing an additional right turn lane in one direction was found to be effective in reducing delay by 27.3% and improving traffic efficiency for the whole intersection.

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Several studies have been carried out on evaluating and improving signalized intersections. Jrew and Abojaradeh (2009) carried out a study to evaluate the operational analysis of Wadi-Saqra intersection in Amman city/Jordan, using HCM and Highway Capacity Software (HCS). For optimization process, the authors utilized the Synchro software to solve the current and future problems depending on different proposed alternatives. It was found that changing traffic signal timing, prohibiting left turn movement, and constructing an overpass for one direction did not improve the LOS. However, constructing two overpasses or one overpass and a tunnel will improve the LOS from F to C (Jrew and Abojarade, 2009). Similar findings have been reported by Joni and Hikmat (2017), where the LOS improved from F to C by implementing the strategy of constructing one overpass in one direction of a signalized intersection in Samawa city/Iraq (Joni and Hikmatt, 2017). Furthermore, Ziboon, et al. (2019) used Synchro 10 software to evaluate Al-FALLAH intersection in Baghdad city/Iraq by analyzing delay time, degree of saturation, and LOS. The authors found that the intersection is performing at LOS F under existing conditions (the year 2018) during peak hours. The authors suggested that the unique alternative to improve the performance of the intersection is the construction of an overpass for Al-Falah Street. After the implementation of the suggested geometric design, the intersection will operate at LOS D with an average delay of 41.3 s/veh in the design year (2038) (Ziboon, Qasim and Yousif, 2019).

Siddiqui (2015) found that optimizing cycle length using Synchro software was effective in reducing average delay by 30–35% for both off-peak and PM peak hours. To solve the current and future traffic congestion in a signalized intersection in Dhaka/Bangladesh, Roy, Barua and Das (2015) utilized VISSIM simulation computer program. The authors recommended four alternative proposals including prohibiting right turning movement at all approaches, changing the signal timing, constructing one overpass for one direction, and constructing two overpasses for two directions. The results showed that the third and fourth alternatives were significant in improving the LOS, however, the third alternative was more cost effective. In addition, in a study to manage traffic control and reduce delay at intersections, Udomsilp et al. (2017) focused on setting the optimal cycle length and helping in the application of a reversible lane that includes two traffic signals in a short distance along the selected road. To show an improvement in travel time, a comprehensive analysis was performed between actual signal timing and optimal cycle length. The travel time results indicated that periodic signal timing control by Synchro during peak hours was better than off-peak hours.

A genetic algorithm (GA)-based signal optimization program is developed by Park, Messer, and Urbanik (1999) during an oversaturated condition. The program optimizes different traffic signal parameters simultaneously including cycle length, green split, off set, and phase sequence. In addition, the intersection's performance was evaluated with Transyt-7F software. The authors found that the GA provided better signal timing plans as compared with Transyt-7F program. Besides, Ratrout and Assi (2019) developed a model to optimize signal timing, intersection space (space optimization and lane allocation), and phasing arrangement together. The authors utilized Transyt-7F, Synchro, and HCS 2010 to assess the developed model. The results showed that optimizing both time and spacing plan together produce lower intersection delay as compared to the optimization of the timing plan only. In Jordan, Al-Allaff et al. (2015) conducted a study to improve traffic management system on a network of two main arterials having eight signalized intersections. Synchro 8 program and HCS 2000 were used to evaluate the performance of each intersection. The evaluation output illustrated that the six intersections were operating at high saturation condition with LOS F and two intersections have LOS D. The authors suggested two alternatives. The first alternative was changing the timing plan and the second alternative included modifying the geometric conditions with changing the timing plan. Based on the analysis of data, it was found that with an improvement in the saturation flow, the LOS of the intersections improved from LOS F to LOS C, D, and E.

Another study focused on average delay and LOS estimation at two three-legged intersections in Mansoura city/Egypt (Ragab and Abo El-Naga, 2019). To develop models and analyze the selected intersections, VISSIM micro-simulation software was used. The authors investigated three strategies; first: Original strategy, second: Optimization of signal cycle time, and third: Increasing of lane width. The simulation results illustrated that the second and third strategies resulted in a reduction in delay and improving the LOS from D to C.

The purpose of this study is to assess the performance of two selected signalized intersections in Duhok city and develop the optimum signal timing and geometric improvement using Synchro 8 software. Delay and LOS of each movement and approach of the intersections and for the whole intersections are evaluated using both HCM procedure and Synchro software. Different alternatives and suggestions are proposed to solve the current and future problems including, creating an overpass, changing the cycle length, adding lanes, and prohibiting approaching traffic. Evaluating, analyzing, and optimizing the existing traffic signal of the intersection are also performed by applying the suggested alternatives with and without changing the geometric conditions using Synchro computer program. The future condition of all the intersections is assessed using traffic growth factor. It is important to note that Synchro software calculates intersection and approach delays either based on Chapter 16 of the HCM 2000 or chapter 31 of HCM 2010. Synchro is a macroscopic traffic signal timing tool that can be utilized to optimize signal timing parameters such as cycle lengths, splits, offsets, and phase order for isolated intersections, and make coordinated traffic signal timing plans for arteries and networks. It has no limitations on the number of links and nodes. Synchro is simple in usage and rapid in modeling (Sabra, Wallace and Lin, 2000). For the mentioned reasons, this program was chosen in this study.

Details of sites selection, collection of traffic volume data, geometric characteristics, signal timing, and assessment approach are described in this paper. Assessment results are also presented and discussed.

II. Study Area Description

The area of the study consists of two intersections with different urban streets. The presence of various entertainment places in addition to the presence of restaurants, schools, mosques, buildings, and shopping centers has increased the traffic and thus increased the traffic congestion. The selected intersections are Zari land intersection which is consisting of four legs and Salahaddin Mosque intersection which is consisting of three legs. Both intersections are located in non-Central Business District area. The geometric plan of the existing intersections is shown in Fig. 1.

III. Data Collection Methods

To evaluate the performance of traffic flow at the selected signalized intersections, both field survey and video recording technique using a fixed camera were used in the present study as data collection method. Two methods were used to identify the main input data required for the HCM and selected software program. In good weather condition and based on the information from Duhok Traffic Directorate, the data were collected at the selected signalized intersections for 3 normal days, from 7:30 AM to 10:30 AM to find the morning peak hour. The 3 days were providing a suitable sample to

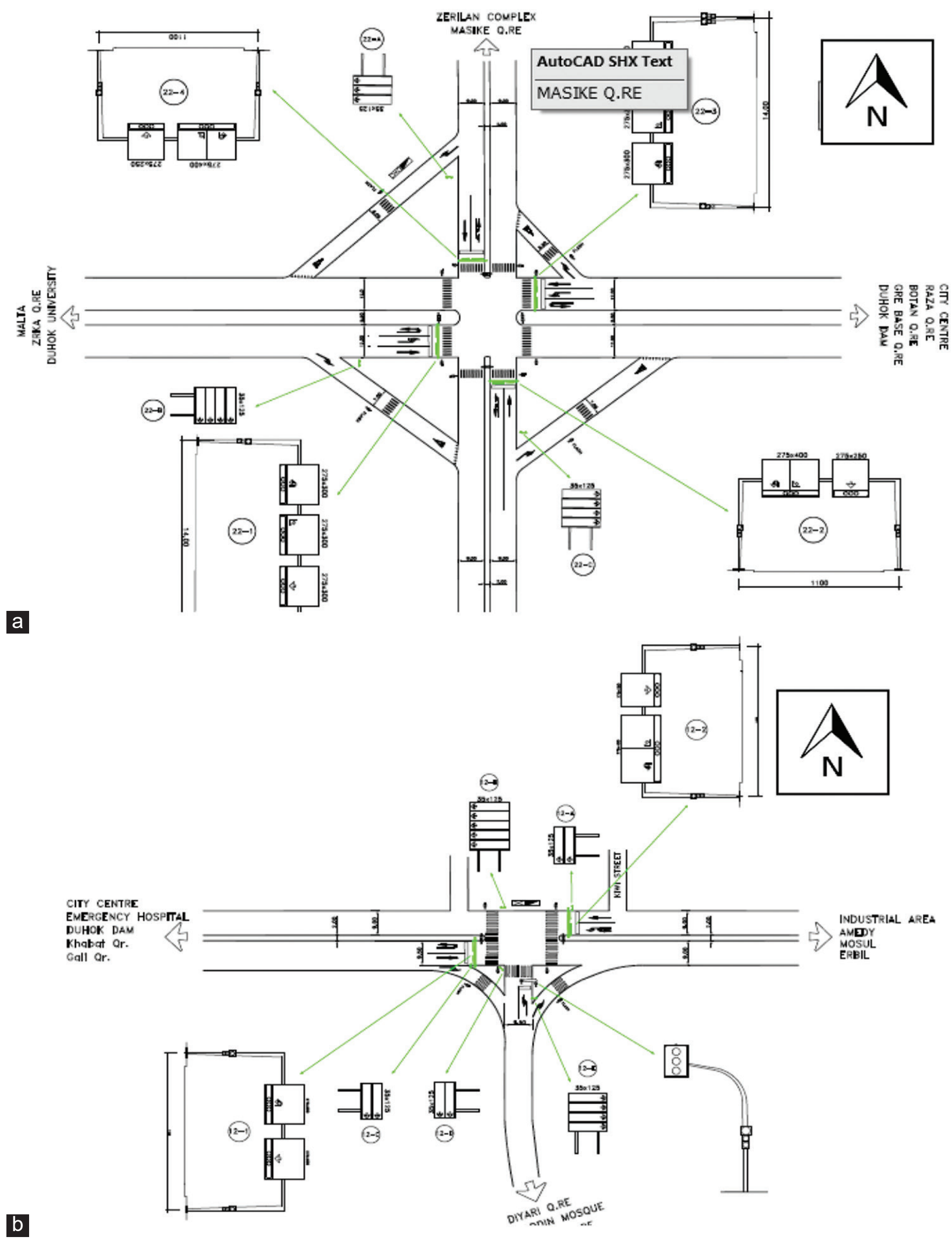

Fig. 1. Geometric plan of (a) Zari land intersection and (b) Salahaddin Mosque intersection.

cover most ranges of traffic conditions under the usual traffic circumstances. A video recording technique using a fixed camera was used in the present study as data collection method for the two selected signalized intersections. Using video recording technique made the selection difficult, as it was necessary to find a good point located on a high place (such as a building) to cover a sufficient approach length (at least 100 m to the stop line). The recorded videos were reviewed and the required data were extracted manually. The advantage of this method is that it allows for a large number of events to be recorded at the same time. The two signalized intersections were visited (field observation) for collecting both geometric characteristics using a measuring tape and recording signal settings using a stopwatch for all approaches of the selected intersections.

A. Traffic Volume Data

Traffic volume data were collected using video recording technique and manual counting of vehicles from the recorded data for 3 normal days from 7:30 AM to 10:30 AM for each 15 min interval to find the variation of flow and determine the peak and off-peak hours. The count started and ended at the same time at each approach. The data collected covers:

1. Traffic volume with composition to indicate % of heavy vehicles
2. Traffic volume with turn types (through, left turn and right turning traffic volume) counts to indicate the proportion of the left and right turn movements
3. In this study, the highest peak hour volume in the morning hours is selected for each approach in the intersection to simulate the worst situation in the intersection to be used in the capacity analysis based on the peak hour factor (PHF) of each approach and in the capacity analysis based on the PHF of each movement
4. Growth rate of traffic volume.

B. Geometrical Characteristics and Signal Timing Data

In addition to the traffic data, geometric data should be collected as input during the optimization process by Synchro software. Field survey and manual method characterized using a measuring tape are also used in this study to collect the required geometric characteristics of each intersection. The geometric characteristics include area type, approach width, number of approach lanes, presence of median, width of median, presence of shared lane on each approach, right turn channelized or not, right turn control type (yield, signal, and free), presence of bus stop, and parking. Signal timing data including type of control, total cycle length, green, yellow, red time, all red (clearance interval), and phase plan were obtained from signal indication during the field survey by a stop watch.

IV. Results and Discussion

The peak hour volume and the PHF for each approach were found from manual counting of the traffic volume data from video recording technique. The PHFs for all approaches and each movement within each approach for Zari land intersection and Salahaddin Mosque intersection is given in Table I.

A. Evaluation of Existing Condition

The analysis was performed based on the existing traffic volumes, signal timing, and geometric configurations for both intersections using the (HCM, 2010) steps and Synchro software. The ratio of demand flow rate to capacity (v/c), average control delay, and LOS are the main performance indices in the evaluation process with HCM 2010 and Synchro software. Operational analysis or determination of LOS based on HCM 2010 includes; input values (considering details of intersection flows, signalization), and geometrics, volume adjustment, saturation flow rate, capacity analysis, delay computation, and LOS. The results of movement delay calculation for Zari land intersection in Table II illustrated that the intersection is operating at LOS F with high intersection delay (747) s/veh during the morning peak hour.

It can be seen that the delay level is unacceptable for EB, which may be due to inadequate phase plan and distribution of green time and more specifically due to low number of lanes allocated for the through movement and capacity problems. In general, the delay is high, and the demand is over capacity. This is due to the reason that the delay may increase rapidly with minor changes in the demand when comparing the WB and EB situations. For the application of Synchro software, the abstracted and collected data required for the software were fed into the program for each movement, each approach, and for the whole intersection. The existing peak traffic flow in Synchro software is shown in Fig. 2.

Table I
PHF Values for Zari Land Intersection and Salahaddin Mosque Intersection

PHF Values for Zari land Intersection			
Direction	PHF by approach	Movement	PHF by movement
NB	0.92	L	0.94
		TH	0.88
		R	0.94
SB	0.91	L	0.89
		TH	0.83
		R	0.88
WB	0.94	L	0.84
		TH	0.93
		R	0.84
EB	0.88	L	0.85
		TH	0.95
		R	0.79
PHF values for Salahaddin Mosque intersection			
Direction	PHF by approach	Movement	PHF by movement
NB	0.85	L	0.81
		R	0.86
WB	0.95	L	0.89
		TH	0.83
EB	0.84	L	0.90
		TH/R	0.94

TABLE II
HCM 2010 CALCULATIONS BY MOVEMENT – ZARI LAND INTERSECTION

Hand calculations by movement											
Direc/LnGrp	v/c Ratio	g/c Ratio	Unif Delay d1 (sec)	Progr Fact PF	Lane Grp Cap	Cal Term k	Incr Delay d2 (sec)	Lane Grp Delay	Lane Grp LOS	Delay by APP (s/veh)	LOS by App
WB/L	0.66	0.27	71	1	770	0.5	4.4	75.4	E	459	F
WB/TR	2.31		78	1	392	0.5	597	675	F		
EB/L	0.48	0.20	72	1	663	0.5	2.48	74.5	E	1266	F
EB/TR	4.19		81	1	348	0.5	1442	1523	F		
SB/L	1.46	0.22	81	1	395	0.5	221	302	F	278	F
SB/TR	1.34		81	1	384	0.5	170	251	F		
NB/L	0.90	0.19	71	1	497	0.5	22	93	F	201	F
NB/TR	1.44		74	1	472	0.5	210	284	F		
Intersection										747	F

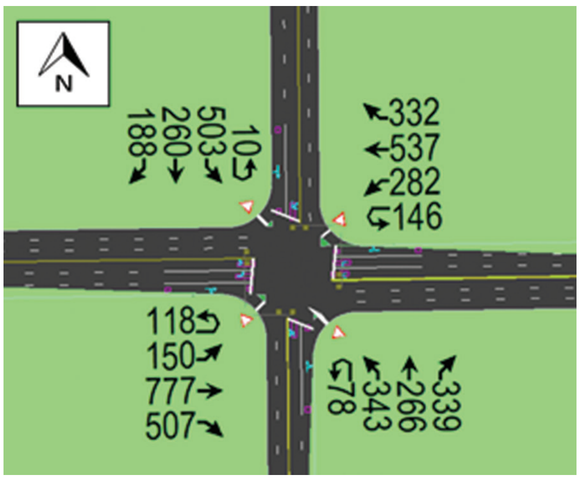

Fig 2. The existing peak traffic flow in Synchro software – Zari land intersection.

Assessment of the average delay per vehicle in each lane group, each approach, and for the whole intersection (operational analysis by movement) is shown in Table III. The results illustrated that the intersection is operating at LOS F with a high delay (589.8) s/veh during the morning peak hour.

The results of HCM application for movement delay calculation for Salahaddin Mosque intersection in Table IV illustrated that the intersection is operating at LOS F with a high delay (608.9) s/veh during the morning peak hour. The v/c ratio of the through movement is much higher than that of the left turn movement at both WB and EB. This imbalance results in much higher delay experienced by one movement than the other.

The average delay time of the left movement for both WB and EB approaches was 33.2 and 30.4 s/veh, respectively, which is equivalent to the LOS C and indicates that the traffic continues smoothly or the approach green time is reasonable for the volume in left movements. However, the extremely high average delay through movements likely indicates a breakdown of vehicular traffic flow. The HCM delay model produces reasonable results for undersaturated conditions but compared to other delay models, predicts higher delays for oversaturated conditions. The existing peak traffic flow in Synchro software is shown in Fig. 3.

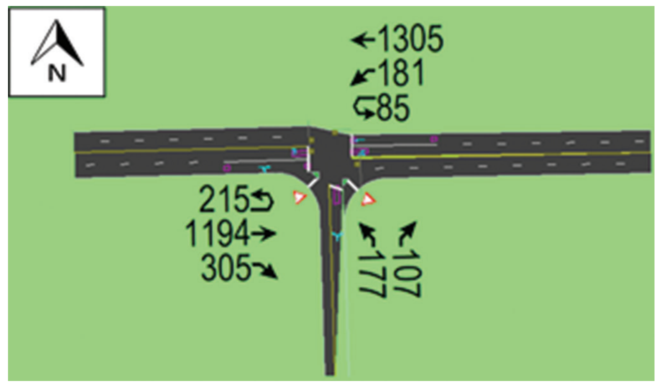

Fig. 3. The existing peak traffic flow in Synchro – Salahaddin Mosque intersection.

Assessment of the average delay per vehicle in each lane group, each approach, and for the whole intersection (operational analysis by movement) is shown in Table V. The results illustrated that the intersection is operating at LOS F with high a delay (544.3) s/veh during the morning peak hour. Similar to the Zari land intersection, the result of delay analysis for Salahaddin Mosque intersection using both HCM 2010 and Synchro software applications indicates a nearly reasonable matching between the software generated and the calculated delay values using movement analysis.

In general, the analysis results of both intersections by HCM 2010 procedure and Synchro software application indicate a nearly reasonable matching between the software generated delay and the calculated delay values using movement analysis. However, a comparison is made by the paired samples t-test using SPSS V.27 program to determine whether there is a difference between average delay calculated by HCM and Synchro software (Synchro, 2011). The results indicate that there is no statistically significant difference between two mean values of delay with mean of delay difference of 21.38 s and $P = 0.23$. The difference between both results may be due to the reason that although Synchro computes control delay for the signalized intersections according to the HCM method, it offers an alternative calculation of delay based on an expected distribution of traffic volumes for the intersection which is called the percentile delay for different traffic volume levels to differentiate it from the HCM control delay.

Table III
Synchro Application by Movement – Zari Land Intersection

Synchro by movement								
Direc/LnGrp	v/c ratio	G/C RATIO	Progr Fact PF	Cal Term k	Ln Grp Delay	Ln Grp LOS	Delay by APP (s/veh)	LOS by App
WB/L	0.48	0.27	1	0.5	82.2	F	1182.9	F
WB/TR	4.11		1	0.5	583.7	F		
EB/L	0.64	0.20	1	0.5	76.8	E	404.3	F
EB/TR	2.21		1	0.5		F		
SB/L	1.57	0.22	1	0.5	313.5	F	276.3	F
SB/TR	1.36		1	0.5	233.3	F		
NB/L	0.95	0.19	1	0.5	100.8	F	172.5	F
NB/TR	1.36		1	0.5	222.9	F		
Intersection							589.8	F

Table IV
HCM 2010 Calculations by Movement – Salahaddin Mosque Intersection

Hand calculations by movement											
Direc/LnGrp	v/c Ratio	g/c Ratio	Unif Delay d1 (sec)	Progr Fact PF	Lane Grp Cap	Cal Term k	Incr Delay d2 (sec)	Lane Grp Delay	Lane Grp LOS	Delay by APP (s/veh)	LOS by App
WB/L	0.47	0.353	30.7	1	635	0.5	2.5	33.2	C	721.4	F
WB/T	2.76	0.353	39.5	1	655	0.5	796.3	835.8	F		
EB/L	0.34	0.353	29	1	692	0.5	1.4	30.4	C	562.8	F
EB/TR	2.33	0.353	39.5	1	685	0.5	603.1	642	F		
NB/LR	1.15	0.148	52	1	291	0.5	99.6	151.6	F	151.6	F
Intersection										608.9	F

Table V
Synchro Application by Movement – Salahaddin Mosque Intersection

Synchro by movement								
Direc/Ln Grp	v/c Ratio	g/c Ratio	Progr Fact PF	Cal Term k	Ln Grp Delay	Ln Grp LOS	Delay by APP (s/veh)	LOS by App
WB/L	0.48	0.35	1	0.5	33.8	C	562.9	F
WB/T	2.42	0.35	1	0.5	665.6	F		
EB/L	0.37	0.35	1	0.5	31.5	C	593.2	F
EB/TR	2.45	0.35	1	0.5	677.4	F		
NB/LR	1.22	0.15	1	0.5	169.8	F	169.8	F
Intersection							544.3	F

It computes the uniform delay (d1) for the 90th percentile volume, the 70th percentile volume, the 50th percentile volume, the 30th percentile volume, and the 10th percentile volume. For instance, if the traffic is observed for 100 cycles, the 90th percentile would be the 90th busiest. The five delay calculations are averaged to find the average delay (Siddiqui, 2015). Furthermore, running the Synchro models with default parameters contributes to the difference between both delays estimations.

B. Optimization of the Existing Conditions

Synchro software provides good improvement in reducing the intersection delay and improving the LOS through optimization and implementation of suitable alternatives. The optimization results include some major and important measures of effectiveness such as degree of saturation, intersection delay, and LOS. As there is a nearly reasonable agreement for the results of delay analysis by movement between HCM (2010) calculation and Synchro 8, the existing Synchro models obtained from analysis by movement were optimized using the optimization tool within Synchro. The improvement suggestions for both intersections with their output results are presented in the following sections.

The improvement proposals of the Zari land intersection

Zari land intersection runs as nearly 590 s/veh as average delay and at LOS F. The intersection is oversaturated and considered unsafe. Hence, an improvement scenario must be implemented. According to the HCM (2010), the situation of the intersection is critical when both delay levels and v/c ratios are unacceptable. Therefore, the full range of possible geometric and signal design improvements should be considered as suggestions. Different improvement scenarios were proposed for this purpose such as:

1. Proposal 1: Optimization by changing the cycle length
2. Proposal 2: Optimization by adding a lane for through movement for all approaches
3. Proposal 3: Optimization by changing the cycle length and adding a through lane for all approaches
4. Proposal 4: Optimization by creating an overpass for the main street

5. Proposal 5: Optimization by creating an overpass for the main street, changing the cycle length, and adding a left turn lane for WB and EB and adding a through lane for SB and NB.

The optimization by changing the geometric elements started by adding a lane either for through movement in the major street or for the left turning movement in the minor street. From the field survey measurements, it was observed that the number of lanes in these approaches can be increased by decreasing the lane width (with keeping the width of lanes greater than a minimum value of 2.4 m as recommended by HCM [2010]) which is actually practicable in the field. This is done in Synchro by remarking the approaching lanes and setting the lane width to the maximum allowable width for each approach. This certainly will result in rearranging of queuing vehicles at the stop line. Optimization by creating an overpass for the main street (WB-EB) was another proposal. This proposal was applied as this intersection suffers from high traffic volume and particularly at the through movement. Furthermore, there is an enough space for constructing the overpass. Creation of an overpass was more effective when both cycle time optimization and adding an extra lane for through movement in the main street and a lane for the left turning movement in the minor street were implemented.

The results of all proposed improvements for the existing condition and after optimization for all approaches of this intersection are illustrated in Table VI. The intersection results for cycle length, delay, reduction in delay, and LOS from the base scenario and different optimization methods are reported in Table VII. Comparing to the existing condition, the delay has been decreased considerably and it can be noticed that for the proposals 1, 2, 3, and 4, the delay values have been reduced by 16.72%, 79.41%, 81.79%, and 76.03%, respectively. However, the intersection is still operating at LOS F. The reason behind this is the excessive number of vehicles that cannot be accommodated sufficiently by the intersection and particularly by the insufficient number of the left turn lanes in the main street (WB-EB) and through lanes in the minor street (NB-SB). The reduction in delay is more evidence in proposal 5 indicating 93.37% of reduction resulting the better improvement in LOS values from F to D according to LOS criteria for signalized intersections given in HCM (2010).

The improvement proposals of the Salahaddin Mosque intersection

Salahaddin Mosque intersection runs as nearly 545 s/veh as an average delay and at LOS F. The intersection is oversaturated, and therefore, an improvement scenario must be implemented. Different improvement scenarios were proposed for this purpose such as:

1. Proposal 1: Optimization by changing the cycle length
2. Proposal 2: Optimization by adding a lane for through movement for the main street and adding an exclusive left turn lane for the minor street
3. Proposal 3: Optimization by changing the cycle length and adding a through lane for the main street and adding an exclusive left turn lane for the minor street

TABLE VI
PROPOSED IMPROVEMENTS FOR THE EXISTING CONDITION AND AFTER OPTIMIZATION – ZARI LAND INTERSECTION

Suggested proposal	Delay (s/veh)				LOS			
	WB	EB	NB	SB	WB	EB	NB	SB
Existing condition	1182.9	404.3	172.5	276.3	F	F	F	F
Proposal 1	439.6	660.9	368.6	402.8	F	F	F	F
Proposal 2	86.2	164	74.8	144.7	F	F	E	F
Proposal 3	109.9	88.3	94.6	148.8	F	F	F	F
Proposal 4	51.4	27.6	172.5	276.3	D	C	F	F
Proposal 5	36.3	19.4	41.5	54.4	D	B	D	D

4. Proposal 4: Optimization by changing the cycle length, adding a lane for through movement for the main street, and prohibiting approaching traffic from NB.

The results of all proposed improvements for the existing condition and after optimization for all approaches of this intersection are illustrated in Table VIII. The intersection results for cycle length, delay, reduction in delay, and LOS from the base scenario and different optimization methods are reported in Table IX. Comparing to the existing condition, the delay has been decreased considerably and it can be noticed that for the proposals 1, 2, and 3, the delay values have been reduced by 7.31%, 69.68%, and 73.14%, respectively. However, the intersection is still operating at LOS F. This is due to the reason that the larger number of phases in a traffic light results in a longer waiting time and having a lower share of green time. Therefore, prohibiting the approaching traffic from NB (the minor street with left and right turn only) will certainly increase the capacity of the intersection after sharing the green time of this approach between two other approaches of the intersection.

The reduction in delay is more evidence in proposal 4 indicating 87.12% of reduction resulting the better improvement in LOS values from F to E. The proposal 4 is implemented in Synchro by remarking the approaching lanes and setting the lane width to the maximum allowable width for each approach in addition to optimizing the cycle length and prohibiting approaching traffic from NB. This certainly will result in rearranging of queuing vehicles at the stop line.

C. Evaluation of the Future Condition

The future traffic volume expected to use the highway facilities should be taken into consideration in the design of new highways or implementation of improvements to the existing facilities. To make accurate estimates for future, usually, a period of 15–20 years is used in calculation of growth factor or traffic forecast factor. Synchro software is used to analyze the future data for both intersections based on proposals 5 for Zari land intersection and proposal 4 for Salahaddin Mosque intersection with the “3%” traffic growth factor. Zari land intersection under the proposed improvement of optimization by creating an overpass for the main street, changing the cycle length, and adding a left turn lane for WB and EB and adding a through lane for SB and NB was evaluated for the future traffic volume using Synchro software. Based on the proposal 5 and 3% of traffic

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Table VII
Average Delays and LOS for Existing and Different Improvement Scenarios – Zari Land Intersection

Synchro output	Existing condition	After optimization				
		Proposal 1	Proposal 2	Proposal 3	Proposal 4	Proposal 5
Cycle length (sec)	198	150	198	150	198	120
Max V/C ratio	4.1	2.71	1.5	1.2	1.57	0.86
Delay (s/veh)	589.8	491.2	121.4	107.4	141.4	39.1
Reduction in delay %		16.72	79.41	81.79	76.03	93.37
LOS	F	F	F	F	F	D

Table VIII
Proposed Improvements for the Existing Condition and After Optimization – Salahaddin Mosque Intersection

Suggested proposal	Delay			LOS		
	WB	EB	NB	WB	EB	NB
Existing condition	562.9	593.2	169.8	F	F	F
Proposal 1	514.5	544.3	229.4	F	F	F
Proposal 2	181.3	168.9	50.8	F	F	D
Proposal 3	141.5	163.9	76.3	F	F	E
Proposal 4	61.2	79.3		E	E	

Table IX
Average Delays and LOS for Existing and Different Improvement Scenarios – Salahaddin Mosque Intersection

Synchro output	Existing condition	After optimization			
		Proposal 1	Proposal 2	Proposal 3	Proposal 4
Cycle length (sec)	122	150	122	150	140
Max V/C ratio	2.45	2.32	1.38	1.31	1.09
Delay (s/veh)	544.3	504.5	165	146.2	70.1
Reduction in delay %		7.31	69.68	73.14	87.12
LOS	F	F	F	F	E

growth factor, the intersection will operate at LOS F with an average control delay of 484.7 s. Although the intersection will be under worst operating condition with LOS F, there will be 17.82% reduction in delay comparing to the existing condition for the upcoming 15 years based on the improvement suggested in proposal 5. Salahaddin Mosque intersection under the proposed improvement of optimization by changing the cycle length and prohibiting approaching traffic from NB was evaluated for the future traffic volume using Synchro software. Based on the proposal 4 and 3% of traffic growth factor, the intersection will operate at LOS F with an average control delay of 865.3 s. It was found that no benefit could be obtained by optimizing the cycle length and prohibiting approaching traffic from NB for future condition as compared to the existing condition.

V. Conclusion

At present, transportation authorities have to implement effective countermeasures to resolve the existing congestion problems and improve the traffic operation of signalized intersections. Effective traffic signal control is essential to ensure smooth and arranged traffic operation of urban roads. In this study, traffic performance of two signalized intersections during morning peak hour is evaluated and optimized based on the methodology in the (HCM) 2010 and Synchro 8 software. It has been confirmed that the current state of the intersections exhibits weak performance, due to the extreme values of vehicular waiting times (delay) that have been detected. Zari land intersection using HCM 2010 methodology is estimated to be operating at LOS F with a delay of 747 s/veh and at LOS F with a delay of 589.8 s/veh when using Synchro software. For Salahaddin Mosque intersection, the HCM results illustrated that the intersection is operating at LOS F with a delay of 608.9 s/veh, whereas from Synchro software, the intersection is operating at LOS F with delay of 544.3 s/veh. Several proposals were assessed for both intersections to improve traffic operation such as changing the cycle length, adding lanes, creating an overpass, and prohibiting approaching traffic.

Compared to the baseline scenario or existing conditions, for Zari land intersection, the delay has been decreased considerably and it was found that for the alternative proposals; 1, 2, 3, and 4, the delay values have been reduced by 16.72%, 79.41%, 81.79%, and 76.03%, respectively. However, the intersection is still operating at LOS F. The reduction in delay is more evidenced in proposal 5 with 93.37% of reduction and an improvement in LOS from F to D. For Salahaddin Mosque intersection, the delay has been decreased considerably and it was found that for proposals 1, 2, and 3, the delay values have been reduced by 7.31%, 69.68%, and 73.14%, respectively. However, the intersection is still operating at LOS F. It also indicated that implementing the proposal 4 improved the intersection LOS from F to E, with a significant decrease in control delay of 87.12|% and volume to capacity ratio.

Synchro software was used to analyze the future data for both intersections based on proposal 5 for Zari land intersection and proposal 4 for Salahaddin Mosque intersection with the traffic growth factor of 3%. It was found that the Zari land intersection will operate at the LOS F with 17.82% reduction in delay compared to current condition. Furthermore, the Salahaddin Mosque intersection will operate at the LOS F and no benefit could be obtained by optimizing the cycle length, adding a lane for through movement of the main street, and prohibiting approaching traffic from NB for future condition as compared to the current condition. The situation of the intersection is critical when both delay levels and v/c ratios are unacceptable. Therefore, the full range of possible geometric and signal design improvements should be considered as suggestions. It can be concluded that the approach used in evaluating the existing condition and optimization methods used herein proved to be successful in addressing the study objectives. A future extension of this work should be performed to evaluate the traffic performance for other types of intersections that have not been considered in this study such as network analysis and coordinating intersections.

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