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Analysis of the Operational Performance of Three Unconventional Arterial Intersection Designs: Median U-Turn, Superstreet and Single Quadrant

Hana Naghawi, Khair Jadaan, Rabab Al-Louzi, Taqwa Hadidi

Abstract**—**This paper is aimed to evaluate and compare the operational performance of three Unconventional Arterial Intersection Designs (UAIDs) including Median U-Turn, Superstreet, and Single Quadrant Intersection using real traffic data. For this purpose, the heavily congested signalized intersection of Wadi Saqra in Amman was selected. The effect of implementing each of the proposed UAIDs was not only evaluated on the isolated Wadi Saqra signalized intersection, but also on the arterial road including both surrounding intersections. The operational performance of the isolated intersection was based on the level of service (LOS) expressed in terms of control delay and volume to capacity ratio. On the other hand, the measures used to evaluate the operational performance on the arterial road included traffic progression, stopped delay per vehicle, number of stops and the travel speed. The analysis was performed using SYNCHRO 8 microscopic software. The simulation results showed that all three selected UAIDs outperformed the conventional intersection design in terms of control delay but only the Single Quadrant Intersection design improved the main intersection LOS from F to B. Also, the results indicated that the Single Quadrant Intersection design resulted in an increase in average travel speed by 52%, and a decrease in the average stopped delay by 34% on the selected corridor when compared to the corridor with conventional intersection design. On basis of these results, it can be concluded that the Median U-Turn and the Superstreet do not perform the best under heavy traffic volumes.

Keywords**—**Median U-turn, single quadrant, superstreet, unconventional arterial intersection design.

I. Introduction

THE supply of highways in urban and suburban areas across Jordan has not kept pace with vehicle growth. It has been reported that during the last 10 years, the number of vehicles has grown from 841,933 vehicles in 2007 to 1,502,420 in 2016 indicating an annual growth rate of about 6.7% [1]. As a result, roadways have become more congested, the average speed has decreased and delay has increased. The social and economic impacts of these traffic related issues are substantial, their direct cost has been estimated to be over 567 million JD in 2006 [2]. Transportation Engineers at Greater Amman Municipality (GAM) have adopted many conventional measures such as signal optimization, double-turn lanes, or even building bypasses for alleviating this problem. However, these measures were found to be expensive, disruptive with limited effect in reducing traffic congestion calling for the need to look for cost-effective alternative methods that can efficiently reduce congestion. The UAID is one of these methods which provides promising solutions for addressing traffic congestion at signalized intersections, and improve operational performance and safety efficiency at intersections. There are several types of UAID which can achieve significant operational and safety improvements. These include Median U-Turn, Superstreet, Jughandle, Quadrant Intersection, Continuous Flow Intersection, Continuous Greet-T, Parallel Flow Intersection, Bowtie, Split Intersection, Centre Turn Overpass, and Roundabouts [3]. The general concept of the UAID is to manage traffic through: 1) emphasizing on through traffic movements along major arterial roads, 2) reducing the number of signal phases, and 3) reducing the number of intersection conflict points through eliminating or rerouting conflicting left turn movements to and from the minor arterial or collector crossroad or by favoring though traffic movement along the major arterial road [4], [5].

The main objective of this research is to evaluate and compare the operational performance of a current conventional intersection design with proposed UAIDs including Median U-Turn, Superstreet, and Single Quadrant Intersection using microscopic simulation platform. The reason for choosing these UAIDs is mainly because they are less confusing to drivers and road users for completing traffic maneuvers as compared to other UAID types. In addition, the selected UAIDs had shown significant improvement of intersection performance when they were implemented elsewhere in the world [3]. For this purpose, the heavily congested Wadi Saqra signalized intersection was selected to be tested for the proposed UAIDs. The effect of using UAIDs was not only tested on Wadi Saqra intersection but also on the arterial road including both surrounding intersections. The analysis was done using SYNCHRO 8 microscopic simulation program. The configuration of each intersection was drawn using AUTOCAD 2010 based on the American Association of State Highway and Transportation officials (AASHTO) specification then it was imported into SYNCHRO model [6].

II. Literature Review

A. Median U-Turn

Median U-Turn (MUT) was constructed by Michigan

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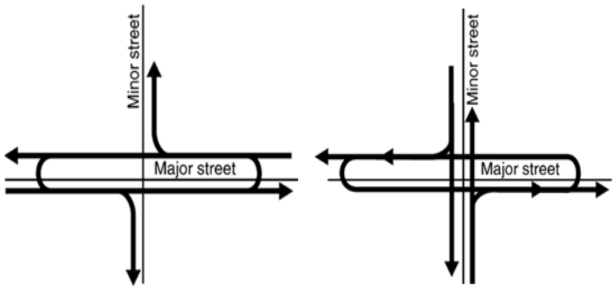
Department of Transportation (MDOT) in 1960's. The MUT is the most common UAID in the USA; it has been implemented successfully in Maryland, Florida, Louisiana and New Jersey [3]. The primary objective of the MUT design is to remove all left turning traffic from the main intersection. Left turn movements are converted to right turns at the intersection then these movements use a unidirectional median crossover to complete their left turn movement as shown in Fig. 1. MUT includes multiple signal illustrations (typically three, one on the main intersection controlled by a two-phase cycle, and one coordinated on each of the two median crossovers). This would favor the major road though traffic because time from the signal cycle does not have to be allocated to protect left turn phases. The design removes or relocates all conflicts that would normally be associated with left turn movements [3].



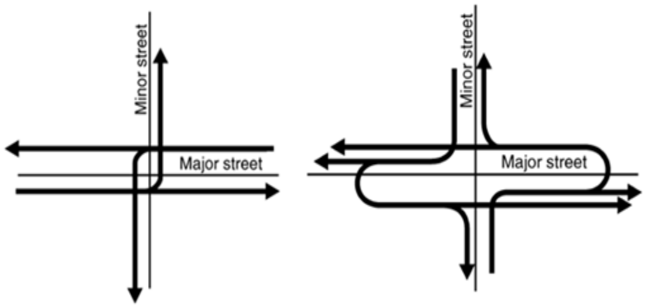
Major Street Movement Minor Street Movement

Fig. 1 MUT Traffic Movements [3]

The MUT has been studied by several researchers. Reid and Hummer compared the MUT design with a conventional intersection design. They constructed a model of a typical corridor in a suburban area near Detroit using real traffic data. The results showed that the MUT intersection reduced system travel time by 17% and increased system speed by about 25% when compared to the conventional intersection [5]. Hummer and Reid reviewed MUT characteristics and summarized new information about the intersection and suggested when it should be feasible to use [7]. Bared and Kaisar compared the MUT with conventional intersection design, the MUT showed a considerable saving in delay time, due to two phase signal with reduction in cycle length also it was found that the capacity has improved by about 18% when compared to the conventional intersection [4].

B. Superstreet

The Superstreet was proposed in the early 1980s by Richard Kramer [3]. It eliminates the through and left-turning traffic from the miner road, by providing U-turns along the main road as shown in Fig. 2. It is a variation of the MUT theme, the primary difference between the MUT and the Superstreet is that the left turning traffic on the major road uses directional median crossover that channels the traffic into the cross street lanes. The effect of this configuration is that it allows the four legged intersection to operate as a two separate three legged intersections as shown in Fig. 2 [3].



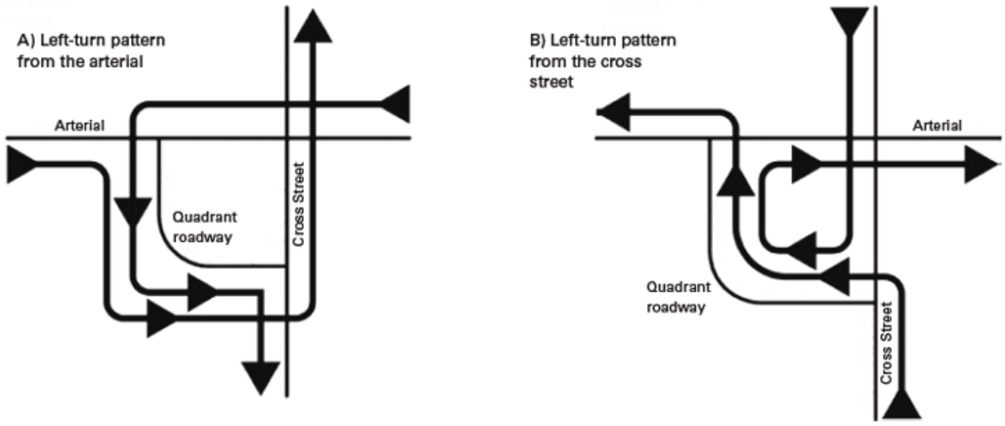
Major Street Movement Minor Street Movement

Fig. 2 Superstreet Traffic Movement [3]

Hummer et al. reviewed the performance of implementing the Superstreet in North Carolina. They noted significant improvement in the operational performance and safety in the Superstreet designs compared to the existing conventional intersection designs [8]. Naghawi et al. used SYNCHRO and VISSIM microscopic simulation software to analyze and compare a proposed Superstreet design to an existing signalized intersection design. It was found that the proposed Superstreet design reduced the average delay per vehicle by up to 87% and reduced the maximum queue length by almost 97%. This resulted in improving the LOS from F to C [9]. Naghawi and Idewu used CORSIM to compare the conventional intersection design to the Superstreet intersection design using 72 hypothetical scenarios based on various levels of congestion. It was found that the conventional design consistently showed evidence of higher delay time and longer queue length compared to the Superstreet intersection design. The network delay was reduced by 82.26% and the average network queue length on the major road through lanes was approximately reduced by 97.50% when the Superstreet design was implemented [10]. From safety point of view, three studies stated a reduction in the number of collisions after implementing the Superstreet intersection design [3], [8], [11].

C. Single Quadrant Intersection

The Single Quadrant Intersection (SQI) is another type of UAID. It is considered as a promising solution for busy intersections. The Single Quadrant roadway intersection removes left turning traffic from the main intersection. It operates using a by-pass road in one of the intersection quadrants that rings the main intersection. Fig. 3 shows traffic movement on SQI. It can be seen that all left turning movements from both roads are completed prior or after the main intersection on the by-pass road. The key component in this configuration is the coordination of the signals at the three intersections. SQI design permits the main intersection to operate on a two-phase cycle. The left turning movements into and out of the quadrant roadway occur during the phase that overlaps the movements at the main intersection, thus eliminating the number of stops required to complete the left turn. Finally, the selection of the length of the quadrant roadway and its location is a trade-off between the amount of storage required for left turn queuing and distance and time required for travelling to the intended direction [12].



Major Road Movement Minor Road Movement

Fig. 3 Quadrant Intersection Traffic Movement [12]

Fig. 4 Prince Shaker Bin Zaid Arterial Road [14]

Several studies were conducted to evaluate the operational performance of SQI. Reid and Hummer compared conventional intersection with SQI performance. The study indicated a 22% significant reduction in the overall travel time. Also, it was found that under high traffic volumes the SQI outperformed the conventional intersection [5]. Hummer and Reid examined the SQI performance using different intersection configurations in North Carolina and Virginia. The results showed that in spite of the longer travel distance for the left-turn, the travel time for left-turn is not considerably greater than the conventional intersection and in case of high traffic volume there is a considerable reduction in travel time during both off-peak and peak conditions [7]. Reid compared SQI to a conventional intersection design and found that the SOI can reduce the system delay by 46%, travel time by 15% and maximum queue length by 88% [13].

III. Site Selection

For the purpose of this study, the heavily congested four legged Wadi Saqra signalized intersection in Amman was selected to be tested for the proposed UAIDs. It is located on Prince Shaker Bin Zaid arterial road. Prince Shaker Bin Zaid arterial road is considered one of the most important and critical arterial roads in Amman because it carries traffic between the most attractive areas in Amman; Alshmesani, Zahran, and Alabdali. The corridor's length is about 2,648 m. It has five intersections spaced by a distance of about 430 m with a posted speed of 70 Km/hr. All these intersections are controlled by fully actuated traffic signals. Fig. 4 shows the selected corridor and the intersections on it, including: 1) Alkindi intersection, 2) Wadi Saqra intersection, 3) Wahbeh Tamari intersection, 4) Villa Rosa intersection, and 5) Arab Bank Intersection. The selection of Wadi Saqra intersection was based on the availability of right of way. The operational efficiency of the conventional signalized intersection on Wadi Saqra intersection was compared to the proposed UAIDs. Also the effect of implementing the UAIDs was tested on a segment of Prince Shaker Bin Zaid arterial road starting from Alkindi three legged intersection to Wahbeh Tamari four legged intersection.

IV. Data Collection

The key traffic data were available from the department of traffic operations at GAM. Traffic data were collected at Alkindi, Wadi Saqra and Wahbeh Tamari intersections on 6/10/2014. The 15-min peak hour volumes occurred in the evening peak between 7:30 and 8:30 pm. The data included traffic volumes on each direction including left and right turning volumes, gradients, and percentages of heavy vehicles (H.V %) as shown in Table I [15]. It can be seen that Wadi Saqra intersection suffers from: the heaviest traffic volume, the steepest grade of -9 %, and the highest PHF of 0.98 among the three selected intersections. This high PHF indicates that the intersection is located in a high density urban area.

V. Base Model Development

The base model development process for the current conventional intersection started after the data were collected and prepared. It was constructed using the existing geometric and traffic data for the selected intersections. The geometric design for the existing intersections was imported into SYNCHRO 8 as DXF file from AUTOCAD draft which was brought from GAM, defining the links length, number of lanes, lane width, approach traffic volumes and cycle length as shown in Fig. 5. The need to develop the base model is important to ensure that the SYNCHRO 8 generated traffic volumes similar to those observed in the field, and to compare the conventional intersection design with UAIDs.

TABLE I
Traffic Data (GAM)

Approach	Eastbound			Westbound			Southbound			Northbound		
Traffic Movement	L	Th	R	L	Th	R	L	Th	R	L	Th	R
Alkindi Intersection												
Volume	1468	1007		-	2010	1700	1202	-	608	-	-	-
PHF		0.931			0.92			0.94			-	
Grade		-6%			5%			-6%			-	
V.H		1.53%			2.02%			1.53%			-	
Wadi Saqra Intersection												
Volume	1622	2097	140	256	1447	1059	697	1002	40	678	249	736
PHF		0.872			0.897			0.868			0.976	
Grade		-3%			-9%			-7%			5%	
V.H		2%			1.3%			3%			3%	
Wahbeh Tamari Intersection												
Volume	528	1580	52	48	1240	55	-	-	363	105	62	25
PHF		0.87			0.82			0.82			0.75	
Grade		2%			-1%			0%			0%	
V.H		1%			2%			4%			1%	

Fig. 5 Base Model

A. Base Model Validation

For any traffic model development, validation is the first and most important step. Model validation is the process to check the extent to which the model is representing reality. There are two methods for model validation; visual and statistical validation. The statistical validation is the most commonly used method in transportation projects [16]. It uses statistical measures as validation keys. These keys are used to quantify the similarity between real and simulated values [17].

Some researchers use Root Mean Square Error (RMSE), Mean Error (ME), Mean Percentage Error (MPE), and the Root Mean Square Percent Error (RMSPE) [17]-[19]. The RMSPE is used to replicate the error as a percentile rate. Other researchers use Thiel's inequality coefficient (U) as a measure to indicate information on the relative error [17], [18]. In this research the statistical validation was based on the (U) coefficient using throughput volume as the validation parameter. The throughput volume is defined as the maximum traffic flow which can be served by a lane [19]. Equation (1) was used to calculate the U coefficient.

$$U = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}(\mathbf{Y_{sim}} - \mathbf{Y_{observed}})^2}}{\sqrt{\frac{1}{N}\sum_{n=1}^{N}(\mathbf{Y_{sim}})^2} + \sqrt{\frac{1}{N}\sum_{n=1}^{N}(\mathbf{Y_{observed}})^2}} \quad (1)$$

where N: Numbers of simulation Run. Y_{sim}: Simulated throughput volume. $Y_{observed}$: Real throughput volume.

In this research a total of 13 simulation runs were executed. The duration of each run was about one hour. The throughput volume on the Prince Shaker Bin Zaid was 5,279 vehicles. The simulated throughput volumes for the 13 simulation runs are shown in Table II.

TABLE II
SIMULATION THROUGHPUT VOLUME

Run ID	Throughput volume
1	6,208
2	6,222
3	6,224
4	6,217
5	6,389
6	5,902
7	5,771
8	5,980
9	6,028
10	5,707
11	7,394
12	7,042
13	7,048

The U value is bonded between 0 and 1, where 0 indicates perfect fit between the observed and simulated measurements, while 1 implies the worst possible fit between them. Based on the data mentioned earlier, the U value was found to be 0.11, this value is less than 0.3 which is the threshold of acceptable U value to attain a high accuracy for the model building [19].

B. Base Model Evaluation

The base model for the selected intersections was evaluated based on the following measures of effectiveness (MOE): LOS in terms of control delay per vehicle (sec/veh) and volume to capacity ratio (v/c). The LOS was used according to the HCM methodologies [20]. The HCM defines LOS as "a qualitative measure describing the operational conditions within a traffic stream and their perception by motorists and/or passengers" while the control delay is defined as the delay caused by control device, this time includes the acceleration and/or deceleration time and time vehicle spends in queue [20]. Volume to capacity ratio is the measure of the capacity sufficiency. It indicates the sufficiency of the physical geometry and signal design for the subjected intersections and movements. Table III shows the base model simulation results for the selected three intersections.

TABLE III
BASE MODEL SIMULATION RESULTS

Alkindi Intersection					
Approach	EB	WB	NB	SB	ALL
Control Delay (sec/veh)	237.9	125.7	-	178.5	
LOS	F	F	-	F	F
v/c	1.68	1.52	-	1.15	
Wadi Saqra Intersection					
Control Delay (sec/veh)	272.4	140.7	1949	153.4	862.2
LOS	F	F	F	F	F
v/c	1.91	1.43	11.16	2.04	
Wahbeh Tamari Intersection					
Control Delay (sec/veh)	65	14	18	32	43
LOS	E	B	B	C	D
v/c	1.09	0.84	0.24	0.79	

Table III shows that the control delay values range from 125.7 sec/veh to 237.9 sec/veh at Alkindi intersection. These values correspond to LOS F on all approaches of Alkindi intersection. It also shows that v/c ratio values range from 1.15 to 1.65 at Alkindi intersection. As for Wadi Saqra intersection, the control delay values range from 140.7 sec/veh to 1949 sec/veh. These extremely high values correspond to LOS F on all approaches. The table also shows high and v/c ratio values on all approaches of Wadi Saqra intersections. The high control delay and v/c ratio values indicate capacity deficiency and system failure as well as inadequate signal timing under the current traffic flow for both intersections. On the other hand, the table shows that the control delay values range from 14 sec/veh to 65 sec/veh at Wahbeh Tamari intersection which corresponds to LOS ranging B to E. The v/c values on Wahbeh Tamari intersection were below 1.00 except for the traffic originating from Wadi saqra intersection.

VI. UAID MODEL DEVELOPMENT

Modeling and simulation of the UAID were carried out according to the AASHTO standards for a passenger car and for a design speed of 70 Km/hr. The analysis was performed in two separate stages as follows:

A. First Stage Analysis

In the first stage, the operational performance of Wadi Saqra intersection was evaluated for the three proposed

UAIDs as an isolated intersection. LOS in terms of control delay and v/c ratio was the selected MOE for this stage of analysis.

1. Median U-Turn

MUT model development replaced Wadi Saqra intersection by two coordinated signals on the main intersection (numbered 2 and 5) and another two signals on the crossovers (numbered 3 and 4) as shown in Fig. 6. Traffic movements on the MUT were designed according to Fig. 1. The configuration of the MUT intersection provided a distance of 200 m between the main intersection and the U-Turns/crossovers with a left turning storage length of 137 m. The simulation results for the MUT intersection operational performance results are shown in Table IV.

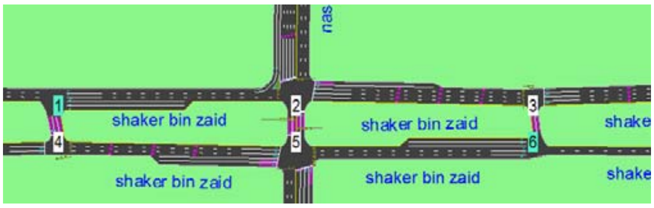


Fig. 6 MUT Simulation Model

TABLE IV
MUT INTERSECTION OPERATIONAL PERFORMANCE RESULTS

Intersection	2*			3*		4*		5*		
Approach	WB	NB	SB	WB	NB	EB	SB	EB	NB	SB
Control Delay (sec/veh)	411.5	2	148	394.5	153	429.4	105.3	315.2	367.3	3.6
LOS	F	A	F	F	F	F	F	F	F	A
v/c	2.5	0.14	1.38	1.88	1.22	1.36	0.97	1.69	1.78	0.40
Intersection Delay (sec)	305.3			314.8		296.3		297		
Intersection LOS	F			F		F		F		

*as shown in Fig. 6ç

TABLE V
SUPERSTREET INTERSECTION OPERATIONAL PERFORMANCE RESULTS

Intersection	1*		3*		5*		7*		
Approach	EB	SB	EB	SB	WB	NB	WB	SB	NB
Control Delay (sec/veh)	121.8	155.2	153.5	167.5	346.7	39.2	236.2	111.1	36.6
LOS	F	F	F	F	F	D	F	F	D
V/C	1.21	1.27	1.26	1.25	1.72	0.89	1.35	1.38	0.41
Intersection Delay (sec)	134.5		156.5		295.7		220.3		
Intersection LOS	F		F		F		F		

*as shown in Fig. 7.

Table IV shows that the control delay on all approaches has decreased compared to the base model results shown in Table III. In spite this reduction, the LOS of the whole intersection did not improve and the intersection is still operating under LOS F, except for the through traffic on the minor road, on which the LOS was improved from F to A. The Southbound control delay was significantly decreased from 153.4 sec/veh on the conventional Wadi Saqra intersection to 3.6 sec/veh, on intersection number 5, on the MUT unconventional intersection design. The Northbound control delay was also significantly decreased from 1949 sec/veh on Wadi Saqra conventional intersection to 2 sec/veh, on intersection number 2, on the MUT unconventional intersection design. Also Table IV shows that the v/c ratio only decreased from 2.04 to 0.14 and from 11.16 to 0.14 on the minor road Southbound and Northbound through movements respectively. As a result, the MUT did not perform as expected and the intersection is still operating under forced conditions. This can be explained by the high through and left-turning traffic volumes on the major road and by the high left turning volume on minor arterial road.

2. Superstreet

The Superstreet model development replaced Wadi Saqra intersection with a two separate T-intersections by preventing the minor road through and left turning movements on the main intersection as shown in Fig. 2. The superstreet model employed two signals on the main intersection (numbered 7 and 3) and another two signals on the crossovers (numbered 1 and 5) as shown in Fig. 7. The crossovers were located approximately 200 m away from the main intersection with 100 m storage length and 15 m taper length. These intersections operate with just two phase signal. The simulation results for the Superstreet operational performance are shown in Table V.

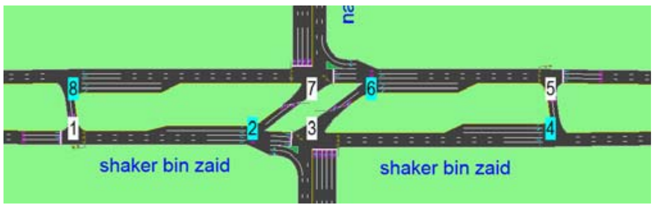


Fig. 7 Superstreet Simulation Model

Table V shows that the control delay on all approaches has decreased compared to the base and MUT model results shown in Tables III and IV, respectively. In spite of this reduction, the LOS of the whole intersection did not improve and the intersection is still operating under forced conditions.

Table V also shows that the traffic operational conditions on the minor road were slightly improved. The Southbound control delay decreased from 153.4 sec/veh on the conventional Wadi Saqra intersection to 111.1 sec/veh, on intersection number 7, on the Superstreet unconventional intersection design, and the Northbound control delay decreased from 1949 sec/veh on the conventional Wadi Saqra intersection to 167.5 sec/veh, on intersection number 3, on the Superstreet unconventional intersection design. Finally, it can be concluded that the Superstreet also did not perform as expected. This can be explained by the high through and left-turning traffic volumes on the major road and by the high left turning volume on minor arterial road.

3. Single Quadrant Intersection

The SQI model adds an additional quadrant roadway between the Eastbound and the Northbound of Wadi Saqra intersection. The additional roadway would move all left turning traffic from the main intersection as shown in Fig. 8. This roadway has a length of 250 m with 110 m parallel offset from Shaker bin Zaid Street. It is controlled by three traffic signals: one two-phase signal at the main intersection and two three-phase signals at the entrance and the exit of the ramp. The simulation results for the SQI are shown in Table VI.

Table VI shows that the control delay on all approaches of the SQI has decreased when compared to the base model, the MUT model and Superstreet model results shown in Tables III, IV and V respectively. It can be seen that the SQI reduced the control delay by 98% on the main intersection which was associated with LOS improvement from F to B, but the by-pass intersections operated under forced conditions with LOS F which implies using grade separation solution to improve the by-pass operation and the overall SQI operation. Also, Table VI shows that v/c ratios on all approaches of the main intersection were less than 1. This indicated that the intersection operated under stable conditions. As a result, the SQI performed the best among the three proposed UAIDs under heavy through and left turning volumes on major and minor arterial roads.

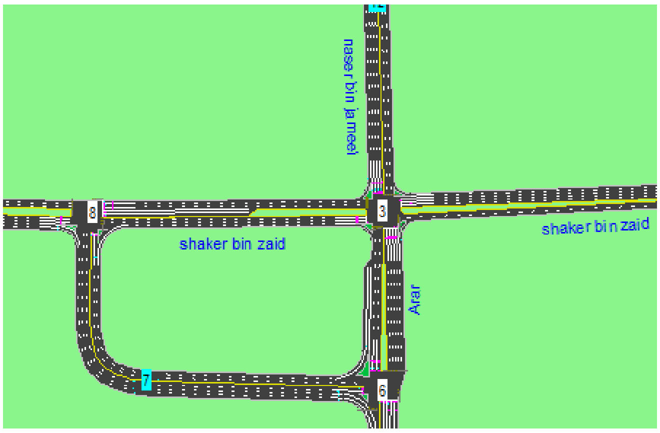


Fig. 8 Single Quadrant Simulation Model

TABLE VI
SQI OPERATIONAL PERFORMANCE RESULTS

Intersection	3*				6*			8*		
Approach	EB	WB	NB	SB	EB	NB	SB	EB	WB	NB
Control Delay (sec/veh)	14.3	26	9.5	17.8	237	1021.2	6	11	104	169
LOS	B	C	A	B	F	F	A	B	F	F
V/C	0.28	0.91	0.57	0.91	1.33	6.49	0.62	0.82	1.32	1.34
Intersection Delay (sec)	17.1				505			109.1		
Intersection LOS	B				F			F		

* as shown in Fig. 8.

B. Second Stage Analysis

At this stage, the operational performance of Prince Shaker Bin Zaid arterial road was evaluated including the main intersection: Wadi Saqra intersection, one prior to the main intersection: Wahbeh Tamari intersection, and one after the main intersection: Alkindi intersection, after implementing the SQI at the main intersection. The MUT and the Superstreet intersection designs were excluded from this stage of analysis since the simulation results, in the first stage, indicated that these two UAIDs did not improve the main intersection performance. The MOEs used to evaluate the operational performance on the arterial road included traffic progression, average stopped delay per vehicle, number of stops, and average travel speed. The analysis was performed using SYNCHRO 8 microscopic software.

Figs. 9 and 10 show the traffic progression for the main arterial road, Prince Shaker Bin Zaid road, for the current conditions and for the SQI design respectively.

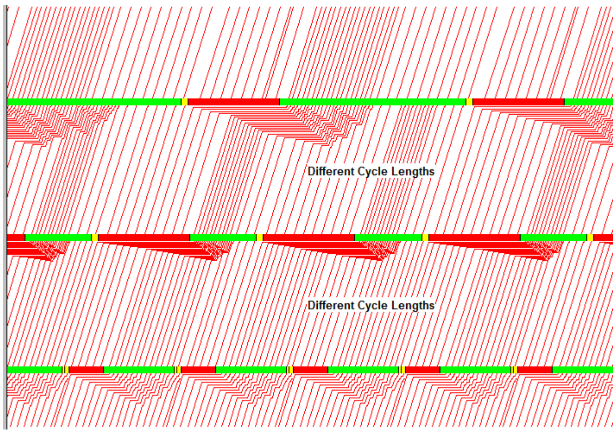


Fig. 9 Traffic Progression for Prince Shaker Bin Zaid under the Existing Conditions

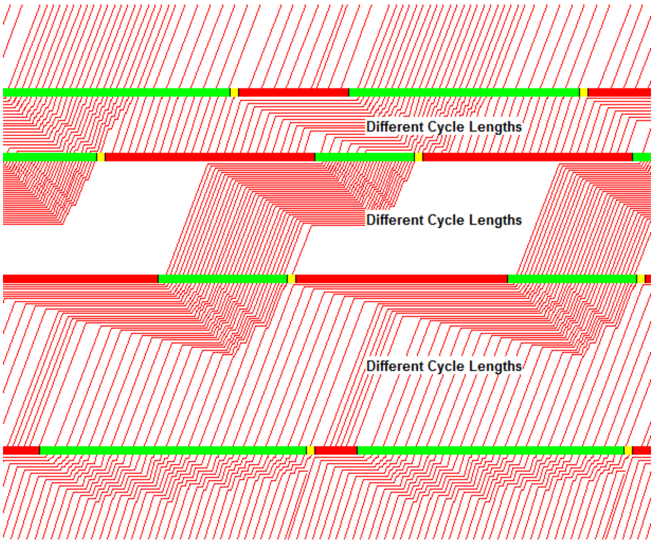


Fig. 10 Traffic Progression for Prince Shaker Bin Zaid with SQI

Figs. 9 and 10 show the traffic flow from Wahbeh Tamari intersection (bottom) to Alkindi intersection (top), the horizontal bars with red, yellow, and green colors indicate signal phases. It can be concluded that the SQI implementation allows a platoon of vehicles to progress with the largest number of stops and the least delay and has favorable traffic progression.

The average stopped delay per vehicle, number of stops per vehicle, and average travel speed were used to compare the entire corridor with the current conventional intersection design and the corridor with the SQI design. Table VII shows the comparison results. The table shows that the average stopped delay per vehicle was reduced by 33.5% and the average travel speed was increased by 52.2%, while the number of stops was increased by 39% when implementing the SQI. This indicates significant improvement in the traffic performance on the selected corridor.

TABLE VII
CORRIDOR COMPARISON UNDER CURRENT AND SQI CONDITIONS

MOE	Corridor under Current Conditions	Corridor With SQI Design
Average Stopped Delay per Vehicle (sec/veh)	137.5	91.1
No. of Stops per Vehicle	1	1.39
Average Travel Speed (km/hr)	23	35

VII. SUMMARY AND CONCLUSION

In this study, the operational performance of three types of UAID were tested and evaluated. The tested UAIDs included MUT, Superstreet, and SQI. To achieve this purpose, the heavily congested Wadi Saqra Signalized Intersection in Amman, the capital of Jordan, was studied. Modeling and simulation of the unconventional intersection designs were carried out according to AASHTO standards for a passenger car and for a design speed of 70 Km/hr. Traffic simulations were conducted for each unconventional intersection design using real traffic data using SYNCHRO 8. The analysis was performed in two separate stages; in the first stage, the operational performance of the studied intersection was evaluated for the three proposed UAIDs as an isolated intersection. The second stage involved an evaluation of the operational performance of the arterial road connecting three intersections; the studied intersection, one prior to it and one after it following the implementation the proposed UAIDs at the studied intersection. In the first stage analysis, LOS in terms of control delay and volume to capacity ratio were used as the MOEs. Traffic progression, stopped delay per vehicle, number of stops and the average travel speed were the MOE selected for the second stage analysis. The simulation results indicated that the MUT and the Superstreet had not shown significant improvement in the operational performance of Wadi Saqra intersection. It also indicated that implementing the SQI improved the intersection LOS from F to B, with a significant decrease in control delay and volume to capacity ratio. Finally the results indicated that the implementation of the SQI design allowed a platoon of vehicles to progress with the largest number of stops and the least delay and have favorable traffic progression, it increased the average travel speed by 52%, and a decreased the average stopped delay by 34% on the selected corridor.

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