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Evaluation of the Performance of using Different Unconventional Intersections at Highly Congested Intersections. Case Study: Amman/Jordan

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Key words: Bowtie intersection, continuous green T-intersection, Jug-Handle intersection, measurement of effectiveness, Micro-simulation, single quadrant roadway, traffic operational performance, unconventional intersections

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Abstract: The main purpose in this study is to attempt to improve the operational performance of highly congested urban arterial intersections by using Unconventional Arterial Intersection Designs (UAIDs) as a solution of congestion intersections. Also, to make comparison between the operational performance of the current situation and the proposed unconventional solutions. In this study signal timing optimization was used as an initial solution before doing any modification on the geometric design. Then, testing the effect of implementing some types of UAIDs including single quadrant, jug-handle, bowtie and Continuous Green T-Intersection (CGTI) as suggested solutions for three highly congested urban arterial intersections in Amman, Jordan. By using microscopic simulation software, Synchro studio 9 with Sim Traffic and using a real traffic data for each intersection. For the purpose of this study the selected intersections were two of four-legged intersection type; Alaqsa Intersection and Ebad Alrahman Intersection and one of three-legged intersection type; Abu Hdeeb Intersection where all of them are complicated intersections. The analysis revealed that the proposed UAIDs succeeded in improving the current intersections where the Level of Service (LOS) improved to be C using Single Quadrant and B using Jug-handle at Alaqsa Intersection, LOS B using Bow-tie at Ebad Alrahman Intersection and LOS D using Continuous Green T-intersection at Abu Hdeeb Intersection.

INTRODUCTION

The growing in population and the increasing of individual requirements will affect the transportation system because of the increased of vehicles, regardless of their types which leads to congestion, delays and safety problems, especially at intersections There are unconventional alternatives may help to solve or mitigate these problems without having to pay a high cost compared to traditional one that will positively affect the road in the future. Unconventional Arterial Intersection Designs (UAIDs) at intersections are more effective at reducing the congestion with low cost than the signalized intersections to increase the operational and safety performance.

However, it should be noted that non-traditional/unconventional solutions are not available to all intersections, so when using them one must consider the shape, location and geometric design of the intersection. It is difficult to impose a specific type of these solutions in a place that needs to demolish buildings adjacent to the intersection. UAIDs should pay close attention to the suitability of these solutions to how closely they are used.

Because of the novelty of UAIDs and their specifications that exceed the non-traditional/ unconventional intersections specifications have become a better solution for congested intersections, for example by Reid and Hummer[1] the Jug-handle alternative was used at a four-legged congested intersection the travel time decreased where that improved the intersection to be better than traditional intersection, so to increase the efficiency of the intersection to suit traffic needs as an alternative solution.

There are limited researches about the unconventional intersections in Jordan as a good alternative for the highly congested signalized intersections because of the limited ROW and these alternatives will confuse the drivers where they need to guidance and training to how to use the new type of intersections. This study will compare between the operational performance of the current situation and the operational performance of the proposed unconventional solutions.

The study area of this study was three highly congested intersections in Amman, Alaqsa Intersection, Ebad Alrahman Intersection and Abu Hdeeb Intersection and these intersections were selected because of their suitable ROW and capability to use UAIDs as effective solutions.

The most likely solutions of UAIDs for the specific study area to use in this study are Single quadrant and Jug-handle at Alaqsa Intersection, Bowtie Intersection at Ebad Alrahman Intersection and Continuous Green T-intersection at Abu Hdeeb Intersection, since, each of the selected intersections is one of the highly congested urban arterial intersections in Amman, where the ROW in these intersections is somewhat adequate to apply these alternatives. In addition of the UAIDs types did a signal optimization as alternative solution.

The main objective of this study is to evaluate the impact of current intersections and proposed solutions on the intersections themselves and surrounding area. And to achieve that a detailed investigation of the comparison data based on multiple Measures of Effectiveness (MOE's) such as average delay, queue length, volume to capacity ratios and other variables to help the researcher decide which option or solution is better.

Synchro studio 9 simulation software, a microscopic software that provides the best in traffic analysis, optimization and simulation applications, will be used to build the model of the three intersections in the current situation then try to build other models by using the proposed alternatives. This software gave us results about the Measures of Effectiveness (MOEs) and these MOEs would be used to do a comparison.

Literature review: Now, it is the time to articulate the previous studies that describe the unconventional arterial intersection designs that will be used in this study including the intersection layout, geometric features and vehicle movements.

Conventional intersection treatment: Federal Highway Administration (FHWA) studies have shown that using conventional solutions by increasing the capacity of the roadway will decrease returns, for example, if the addition of a second through lane adds 15 years to the life of the intersection before it reaches capacity, the addition of a third through lane adds only 10 years and a fourth through lane adds only 6 years. In other words, increasing the supply of an intersection that will appears of the users as a more efficient roadway and the demand will be larger, so, the design life of the intersection will decrease.

One of the most important solutions that can be done without modifying the geometric design of the intersection is signal timing optimization; it is a cost-effective solution to reduce congestion. There are many studies on improving the signals timing optimization methodology, depending on the nature of the transport network.

Unconventional Arterial Intersection Designs (UAIDs)
Single quadrant: The single Quadrant Roadway (QR) is one of the UAIDs that used to remove left turn and U-turn movements from the main intersection by using a connector that connects between leg of the major roadway and leg of the minor roadway, Fig. 1 shows the single

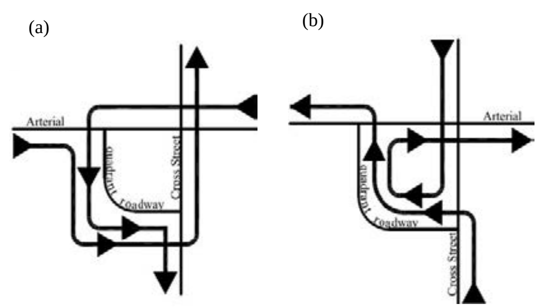

Fig. 1(a, b): Single Quadrant Intersection Left Turning Movements, (a) Left turn pattern form the arterial and (b) Left turn pattern form the cross street

Quadrant intersection left turning movements and how rerouting the left turning movements by using the connector. The location of the connector depends on vehicles traffic flow and the availability of the right of way.

A QR intersection needs three sets of signal controlled junctions the main intersection with two signal phases and two secondary intersections at the ends of the connecting road with three signal phases each.

Reese *et al*.[2], first investigated the implementation of the Single Quadrant Roadway at North Carolina and this study recommended that this solution was a successful solution at this location where the LOS improved, the average delay decreased and the queue length decreased and these results indicate the quadrant roadway is an acceptable alternative to improve the operational performance of the traditional intersection.

Reid [3], developed a monograph with unconventional at-grade and grade-separated intersection designs list to improve highly congested urban arterial intersections. One of the unconventional intersections that discussed in this monograph was QR intersection and showed newer designs yet to be implemented.

Tarko *et al*.[4], studied the safety and performance of the conventional intersections and alternative intersections where the single quadrant was one these alternatives, under Indiana traffic conditions and evaluate these intersections to find the best solutions of the congestion problem and this study resulted that the alternative solutions where used in this study were suitable only under specific roadway geometric conditions.

Jug-Handle: The most prominent user of Jug-handle design is the State of New Jersey, followed by a few other northeastern states. The New Jersey Jug-Handle Intersection (NJJI) is one of the UAIDs that used to remove the left turn movements from the main intersection and the New Jersey Department of Transportation (NJDOT) design manual defines “jug handle” as an at-grade ramp provided at or between intersections to permit motorists to make indirect left turns and/or U-turns. Around-the-block designs that use interconnecting local street patterns to accomplish indirect left turns or U-turns are not considered “jughandles.” These ramps exit from the right lane of the highway in advance of the intersection, or past the intersection and convey traffic across the main highway under traffic signal control. This movement eliminates all turns within active traffic lanes and, in addition to providing greater safety, reduces delays to the through traffic that left-turning vehicles usually create. Figure 2 shows the movements of Jug-handle.

Reid and Hummer[1], compared the travel time of conventional and seven unconventional intersection

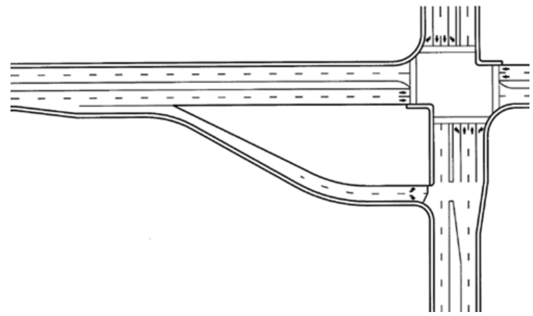

Fig. 2: Jug-Handle

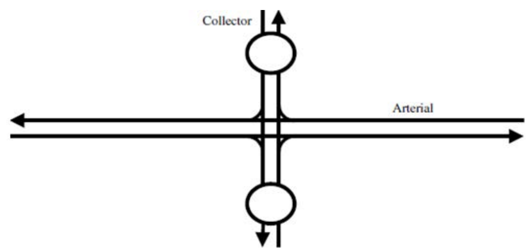

Fig. 3: The Bowtie[5]

designs using data from actual intersections, the Jughandle intersections was one of the seven unconventional intersections. As a result of this research most of the unconventional intersection designs showed improvement in one or more scenarios.

FHWA, published a study to compare the traffic performance of three typical designs of New Jersey Jughandle Intersections (NJJIs) with conventional intersections for a same volume conditions, then showed that NJJIs lead to decrease the average intersection delays and increase the intersection capacities for near-saturated traffic conditions and similar operational performance for under-saturated conditions.

FHWA, developed six alternative intersections and interchanges to solve the traffic problems and to improve the intersections; one of these alternatives was jug-handle intersection. This study resulted that the nontraditional alternatives improved the intersections and promote the traffic by creative and innovative thinking.

Bowtie: The Bowtie intersection is another type of the UAIDs that moves all Left turning from the major street to the minor street by using two mini roundabouts in the minor street as Fig. 3 whereas any vehicle wish to turn left in the major street it should turn right into the minor street and using the roundabout to back to the major street.

The roundabout diameter, including the center island and circulating roadway, varies from 90-300 ft. depending on the speed of traffic on the approaches, the volume of traffic served, the number of approaches and the design vehicle. The distance from the roundabout to the main intersection could vary from 200-600 ft., trading off spillback against extra travel distance for left-turning vehicles. The arterial may have a narrow median[5].

Hummer and Reid[5] reviewed five unconventional intersections, the Bowtie intersection is one of these alternatives, to summarize advantages, disadvantages and when to consider these alternatives. While the Bowtie alternative should be used at high through volumes in the major street with moderate to low through volumes in the minor street and moderate to low left turn volumes.

Hildebrand[6] developed this study to improve through traffic along the arterial road using five types of UAIDs and the Bowtie intersection was one of these types. Where these alternative designs used to remove exclusive left turn lanes from the major road to the minor road to provide a longer green phase for through traffic volumes.

Tarko *et al*.[4], studied the safety and performance of the conventional intersections and alternative intersections where the bow-tie was one these alternatives, under Indiana traffic conditions and evaluate these intersections to find the best solutions of the congestion problem and this study resulted that the alternative solutions where used in this study were suitable only under specific roadway geometric conditions.

Continuous green t-intersection: Continuous Green T-intersection (CGT) is another unconventional alternative that used in this study, this alternative specially used for three-legged intersection while it is not favorable for four-legged intersection. The CGT intersection is also known as Turbo T-intersection, High T-intersection and Seagull intersection.

CGT intersection design is used to let the through travel vehicles pass without stopping in the major street in one side and control the opposite direction by signals, Fig. 4 shows CGT intersection design. The left turning vehicles (in the Top side of the "T") merging from the major street to the minor Street then back to the major street by turn left from the minor street using the channelized lane to merge onto the major street. Sando *et al*.[7], examined and analyzed the safety characteristics of the continuous through lane (in the top side of the "T") using paired t-test and Ordered Probit (OP) statistical models.

Chow and Meuleners, reviewed of the road safety performance of seagull intersections in Australian and international evaluations. The study provided main roads Western Australia and other responsible agencies with comprehensive information about Australian and international reviews/evaluations of seagull intersections. Reid[3], developed a monograph with unconventional at-grade and grade-separated intersection designs list to improve highly congested urban arterial intersections. One of the unconventional intersections that discussed in this monograph was CGT intersection and showed newer designs yet to be implemented. This study resulted that the unconventional intersections were effectiveness when used them as new solution at conventional intersections.

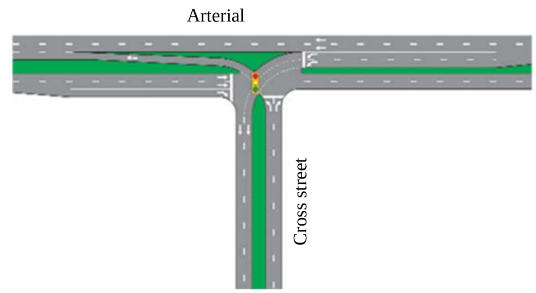

Fig. 4: Continuous Green T-intersection design

Fig. 5: Google Earth Photo of Alaqsa Intersection

Site description: The case study intersections were chosen to achieve the main purpose of this study should be highly congested arterial intersections located in Amman.

The first four-legged arterial intersection located in Dahyet Alaqsa at the intersection of three streets including; Alaqsa Street, Shurhabeel Ben Hasna Street and Shafeek Irshadat Street, this intersection known as Alaqsa intersection. Figure 5 shows Google Earth photo for Alaqsa Intersection.

The second four-legged arterial intersection located in Alswaifyeh at the intersection of three streets including; Princess Alia Bent Al Hussein Street which

Fig. 6: Google earth photo of Ebad Alrahman Intersection

Fig. 7: Google Earth Photo of Abu Hdeeb Intersection

Saeed Al Mufti Street and Jameel Al Tutanji street, this intersection known as Ebad Alrahman intersection. Figure 6 shows Google Earth photo for Alaqsa Intersection.

The three-legged arterial intersection located in Khalda at the intersection of Wasfi Altal Street with Amer Ben malek Street known as Abu Hdeeb Intersection. Figure 7 shows Google Earth photo for Abu Hdeeb Intersection.

MATERIALS AND METHODS

Data collection: The traffic volumes of the selected intersections were available from Traffic Management Control Unit at GAM. Traffic data were collected at Alaqsa intersection and Abu Hdeeb Intersection on 17th of February, 2019 and traffic data were collected at Ebad Alrahman Intersection on 4th of November, 2018. All of these data were collected on the beginning of the week whereas the congestion is high at the study area.

All models of this study were depending on the am peak hour for each direction. The data including Left Turn (LT), U-turn, Right Turn (RT) and Through (THR) volumes, percentage of Heavy Vehicles (HV %) and the Peak Hour Factor (PHF) for each direction, Table 1-3 show these data.

Fig. 8: The base model development of Alaqsa Intersection using synchro

Fig. 9: The base model development of Ebad Alrahman Intersection using synchro

Base model development: Developing three base models for the selected intersections (Alaqsa Intersection, Ebad Alrahman Intersection and Abu Hdeeb Intersection) using the existing geometric and traffic data where were gotten from GAM, whereas these data were imported manually into Synchro studio 9. Defining links length, number of lanes, lanes width, traffic volumes for approaches and cycle length for each intersection. Figures 8-10 show the base models for each selected intersection whereas Fig. 8 shows the base model of Alaqsa Intersection, Fig. 9 shows the base model of Ebad Alrahman Intersection and Fig. 10 shows the base model of Abu Hdeeb Intersection.

Table 1: Alaqsa Intersection traffic data at 8:00-9:00 am peak hour (GAM)

	Northbound (NB)			Southbound (SB)			Westbound (WB)			Eastbound (EB)		
Approach	U-turn	LT	THR+RT	U-turn	LT	THR+RT	U-turn	LT	THR+RT	U-turn	LT	THR+RT
Volumes (vph)	442	489	947	218	275	541	53	53	218	96	96	381
PHF	0.83	0.86	0.85	0.87	0.84	0.93	0.91	0.91	0.77	0.84	0.84	0.91
HV (%)	1.1	1.3	1.3	0.9								

Table 2: Ebad Alrahman Intersection traffic data at 10:45-11:45 am peak hour (GAM)

	Northbound (NB)			Southbound (SB)		Westbound (WB)			Eastbound (EB)	
Approch	LT	THR	RT	LT	THR+RT	LT	THR	RT	LT	THR+RT
Volumes (vph)	388	644	187	135	410	270	477	148	129	359
PHF	0.92	0.99	0.94	0.95	0.88	0.94	0.95	0.88	0.93	0.93
HV %	1	2.2	2.2	0.6						

Table 3: Abu Hdeeb intersection traffic data at 9:15-10:15 am peak hour (GAM)

	Eastbound (EB)			Westbound (WB)			Southbound (SB)	
Approach	U-turn	LT+THR	THR	U-turn	THR	THR+RT	U-turn+LT	LT+RT
Volumes (vph)	428	619	562	528	614	440	145	119
PHF	0.88	0.93	0.95	0.93	0.91	0.85	0.88	0.71
HV (%)	2.1	2.30	3.40					

Table 4: The RE values for all intersections

Intersection name	Alaqsa Intersection	Ebad Alrahman Intersection	Abu Hdeeb Intersection
Average travel time (observed) (sec)	111.81	151.21	126.39
Average travel time (simulated) (sec)	108.34	145.29	121.16
RE (%)	3.1000	3.9200	4.1300

Fig. 10: The Base Model Development of Abu Hdeeb Intersection using Synchro

Models calibration: Model calibration refers to the process of assuring that a model reproduces real-world traffic conditions reasonably well. Micro-simulation models that have not been properly calibrated can produce unrealistic or misleading results. Therefore, before applying the model it is essential for the project manager to assure that it has been properly calibrated.

The selected parameter was the travel time for vehicles traveled on a segment of road whereas the travel time was measured by using stopwatch for ten different vehicles for each intersection and then calculates the observed average travel time, SimTraffic measured the travel time after doing ten runs for the base model of each intersection.

Calculating the Relative percent Error (RE%) to show that if the simulation software that used is similar to the real conditions or not by using Eq. 1. Table 4 shows the resulted relative error for all intersections to note that all of these errors were <10% so, they can be neglected:

$$RE = \frac{\sum_{i=1}^{10}\left(\text{average travel time}_{(\text{observed})}\text{-auerage travel time}_{(\text{simul}}\right.}{\text{Averge travel time}_{(\text{observed})}} \quad (1)$$

Models validation: To develop any model should validate it to check if the model is representing to the reality or not, where the validation is defined as a process used to check to what extent the development model conditions similar to the actual conditions. In this study, the statistical validation was carried out to validate all base models by using the traffic volumes for the whole network as a validation parameter in order to validate the models, all of the base models have been run 100 times for each intersection for 1 h simulation duration. Table 5 shows the simulation traffic volumes of whole network of the selected intersections for 10 runs, while the observed traffic volumes for each intersection were 3809, 3147 and 3455 vph for Alaqsa intersection, Ebad Alrahman Intersection and Abu Hdeeb Intersection, respectively.

Table 5: Part of the simulation traffic volumes of whole network

	Simulation traffic volumes (vph)		
Run ID	Alaqsa Intersection	Ebad Alrahman Intersection	Abu Hdeeb Intersection
1	3826	3111	3504
2	3726	3040	3422
3	3792	2966	3434
4	3898	2951	3442
5	3818	3035	3326
6	3800	3102	3485
7	3878	3033	3442
8	3850	3074	3505
9	3862	3042	3461
10	3786	2979	3577

Table 6: RMSPE for all selected intersections

Intersection	Alaqsa Intersection	Ebd Alrahman Intersection	Abu Hdeeb Intersection
RMSPE	2.26%	3.52%	1.58%

Table 7: Base Models simulation results

	Alaqsa intersection Northbound (NB)			Southbound (SB)			Westbound (WB)		Eastbound (EB)	
Approach	U-turn	LT	Thr+R	U-turn	LT	Thr+R	U-turn+LT	Thr+RT	U-turn+LT	Thr+RT
V/C ratio	0.86	0.91	0.92	0.65	0.85	0.8	0.53	0.61	0.89	0.8
Control delay (sec)	56.4	63.4	54.6	58.5	72.6	58.2	66.7	57.1	92.2	65.1
LOS	E	E	D	E	E	E	E	E	F	E
Max. queue length (m)	136.1	149.6	153.1	63.7	87.5	82.1	30.5	33.6	62.8	54.3

Table 8: Ebad Alrahman intersection

	Northbound (NB)		Southbound (SB)		Westbound (WB)	Eastbound (EB)
Approach	LT	Thr+R	LT	Thr+R	LT+THR+RT	LT+THR+RT
V/C ratio	0.86	0.89	0.72	0.86	0.9	0.9
Control delay (sec)	77.6	70.1	73.6	73.8	82.9	87.4
LOS	E	E	E	E	F	F
Max. queue length (m)	140.8	147.1	93.4	115.5	100.8	91

Several measures can be used to evaluate the simulation model performance; Root Mean Square Error (RMSE), Mean Error (ME), Mean Percentage Error (MPE) and the Root-Mean-Square Percent Error (RMSPE). In this study, RMSPE measure is used to evaluate the three models performance because the effect of each error on RMSPE is proportional to the size of the squared error; thus larger errors have a disproportionately large effect on RMSPE. Consequently, RMSPE is sensitive to outliers and it is calculated as follows:

$$\text{RMSPE} = \sqrt{\frac{1}{N}\sum_{1}^{N}\left(\frac{Y_{\text{simulated}} - Y_{\text{observed}}}{Y_{\text{observed}}}\right)} \quad (2)$$

Where:

RMSPE = The root-mean-square percent error (%)
N = The numbers of simulation Run
$Y_{simulated}$ = The simulation run traffic volume (vph)
$Y_{observed}$ = The real traffic volume (vph)

The RMSPE is calculated for all intersections and found to be <15% which is the RMSPE have high accuracysuch as the models validation, Table 6 shows the RMSPE for all intersections.

Table 9: Abu Hdeeb intersection

Approach	Westbound (WB)	Eastbound (EB)	Southbound (SB)
V/C ratio	0.96	0.94	0.73
Control delay (sec)	58.9	52	66.8
LOS	E	D	E
Max. queue length (m)	181.1	177.9	45.5

Evaluation the base models: The evaluation of all models done by using the Measures Of Effectiveness (MOE) such as; Level of Service (LOS), control delay, maximum queue length and volume to capacity ratio (v/c). The LOS in terms of control delay was used according to the HCM 2010 methodologies where the LOS is defined in terms of a weighted average control delay for the entire intersection. Control delay quantifies the increasein travel time that a vehicle experiences due to the traffic signal control as well as provides a surrogate measure for driver discomfort and fuel consumption.

The volume to capacity ratio (v/c) is a measurement used to measure the adequacy of the intersection or roadway and signal design for the vehicles and movements. Table 7-9 shows the simulation results for all base models.

Table 10: The simulation results after optimizing the base models

	Alaqsa intersection									
	NB			SB			WB		EB	
Approach	U-turn	LT	Thr+R	U-turn	LT	Thr+R	U-turn+LT	Thr+RT	U-turn+LT	Thr+RT
V/C ratio	1.03	1.1	1.1	0.84	1.09	1.02	0.4	0.46	0.78	0.69
Control delay (sec)	86.4	107.5	94.9	66.9	121.3	81.9	43.5	35.3	61.2	43.1
LOS	F	F	F	E	F	F	D	D	E	D
Max. queue length (m)	117.4	132.8	135.3	50.1	75.6	64.8	21.3	22.1	45	37.5

Table 11: Ebad Alrahman intersection

	NB		SB		WB	EB
Approach	LT	Thr+R	LT	Thr+R	LT+THR+RT	LT+THR+RT
V/C ratio	1.12	1.12	0.9	1.03	0.89	0.8
Control delay (sec)	118.9	105.5	69.1	80.1	52.6	44.5
LOS	F	F	E	F	D	D
Max. queue length (m)	89.7	92.4	51.8	66.2	50.6	44.5

Table 12: Abu Hdeeb intersection

	WB	EB	SB
Approach	U-turn+THR+RT	U-turn+LT+THR	U-turn+LT+RT
V/C ratio	1.06	1.13	0.53
Control delay (sec)	73.9	101.6	38.9
LOS	E	F	D
Max. queue length (m)	147.3	158.3	29.3

Table 13: The simulation results of using single quadrant intersection at alaqsa intersection

	Northbound (NB)	Southbound (SB)	Westbound (WB)		Eastbound (EB)		
Approach	THR+R	THR+R	U-turn+LT	THR+R	U-turn+LT	THR	RT
V/C ratio	0.94	0.26	0.40	0.18	0.95	0.61	0.59
Average delay (sec)	28	10	15.9	9.7	49.9	15.9	9.6
LOS	C	B	B	A	D	B	A
Max. queue length (m)	63.4	8.8	7.8	8.4	45.7	39.1	17.8

Evaluation the base models after optimizing: Using the optimizing function in Synchro studio 9 software to optimize the cycle length and the splits gave us new simulation results for each intersection where Table 10-12 shows the simulation results after optimizing for all intersections.

The results of the simulation after optimizing showed that all of the cycle lengths decreased at all intersections, but this optimizing led to increase the intersection delays because this optimizing was only on the cycle length so as a result of this optimizing the queue lengths and the traffic volumes will be more than the acceptable values. The delay at Alaqsa Intersection increased from 61.3-82.5 s and that agreed with LOS F, the delay at Ebad Alrahman Intersection increased from 77-80.3 s and that agreed with LOS F and Abu Hdeeb Intersection average delay increased from 56.4-83.5 s and that agreed with LOS F.

Uaid's models development

Single quadrant intersection: The first alternative proposed at Alaqsa Intersection was pingle quadrant Roadway which this alternative improved the main intersectionby decreased the average delay and improved the LOS, Table 13 shows the simulation results of applying the single quadrant intersection.

The simulation results showed that the control delays at all approaches decreased at the main intersection and because of that the LOS was improved. Remarked that the v/c ratios were <1 and that mean all of these approaches can be accommodated within the current cycle length where the cycle length decreased to be 60 sec at the main intersection.

The LOS at the main intersection was improved from E to C, Fig. 11 shows the LOS at the entrance and the exit of the ramp and the LOS of the main intersection when use the single quadrant intersection. The cycle length of the intersection at the entrance of the ramp is found 150 sec with LOS C and the cycle length at the end of the ramp is found 50 sec with LOS A.

Jug-handle intersection: The first alternative proposed at Alaqsa Intersection was Jug-handle Intersection which this alternative improves the main intersection by decreased the average delay and improved the LOS more than Single Quadrant alternative, Table 14 shows the simulation results of applying the Jug-handle intersection. The simulation results showed that the control delays at all approaches decreased at the main intersection and because of that the LOS improved. Remarked that the v/c ratios were <1 and that mean all of these approaches can

Table 14: The simulation results of using Jug-handle intersection at Alaqsa intersection

	NB	SB		WB		EB	
Approach	THR+R	THR	RT	U-turn+LT	THR+R	U-turn+LT	THR
V/C ratio	0.77	0.6	0.75	0.47	0.23	0.6	0.48
Control delay (sec)	14.3	13.2	8.9	21.3	12.7	22.4	15.1
LOS	B	B	A	C	B	C	B
Max. queue length (m)	47.3	34.5	19.9	8.6	9.3	17.9	23

Table 15: The simulation results of using the Bow-tie intersection

	NB		SB		WB	EB
Approach	THR	RT	THR	RT	THR+RT	THR+RT
V/C ratio	0.42	0.9	0.34	0.62	0.81	0.64
Control delay (sec)	10.7	31.5	10	14.4	21.1	15.3
LOS	B	C	B	B	C	B
Max. queue length (m)	18.7	43	14.4	24.1	38.7	27.2

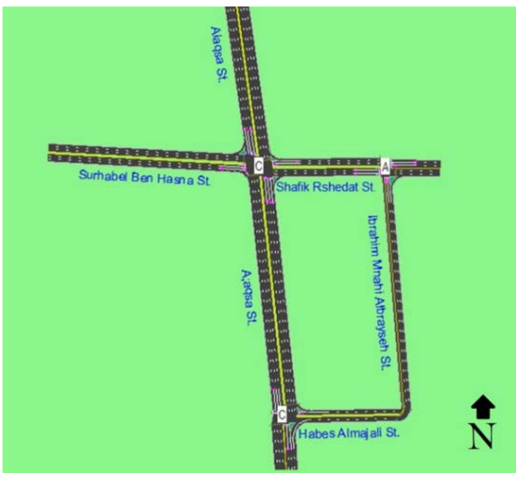

Fig. 11: The LOS at Alaqsa intersection when use single quadrant intersection

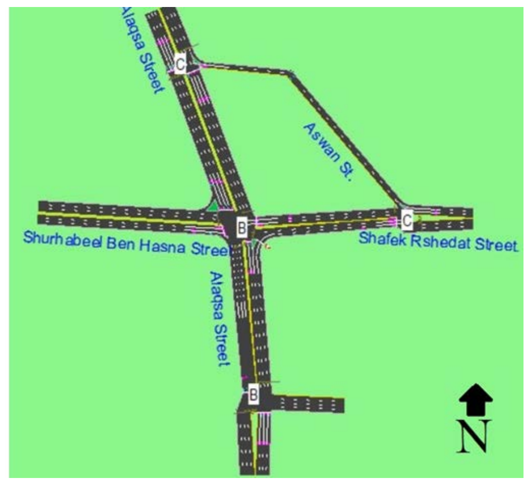

Fig. 12: The LOS at Alaqsa Intersection when use Jug-handle Intersection

be accommodated within the current cycle length where the cycle length decreased to be 55 sec at the main intersection.

These results showed that this alternative is better than Single Quadrant alternative to improve the main intersection, where the average delay at the main intersection decreased to be 13.4 sec and this value agreed with the LOS B while the average delay when used the Single Quadrant intersection was 23.2 sec and this value agreed with the LOS C.

Figure 12 shows the LOS at the entrance and the exit of the ramp and the LOS of the main intersection when use the Jug-handle intersection, where as shown in Fig. 10 the LOS improved at the main intersection from E to B, in addition, the LOS of the intersection at the entrance and the exit of the ramp is C. The cycle length of the intersection at the entrance of the ramp is found 51 seconds with LOS C and the cycle length at the end of the ramp is found 46 sec with LOS C.

Bowtie intersection: The Bow-tie intersection was used as an alternative for Ebad Alrahman intersection, where the roundabouts located at the minor street with 28 m ICD, this alternative improved the intersection LOS and decreased the average delay at all approaches. Table 14 shows the simulation results of using the Bow-tie intersection at Ebad Alrahman Intersection. Using of this alternative helped to remove left turning traffic volumes from the main intersection by using the roundabouts in the minor streets so the LOS changed and improved, Fig. 13 shows the LOS of the intersection when used the Bow-tie Intersection at Ebad Alrahman Intersection.

The continuous green t-intersection: The continuous green t-intersection alternative used as a good solution for three-legged intersections and in this study used CGT intersection for Abu Hdeeb Intersection to improve it and decrease the average delay of the intersection. Table 15 shows the simulation results of using CGT intersection at

Fig. 13: The LOS at Ebad Alrahuman Intersection when use the bow-tie intersection

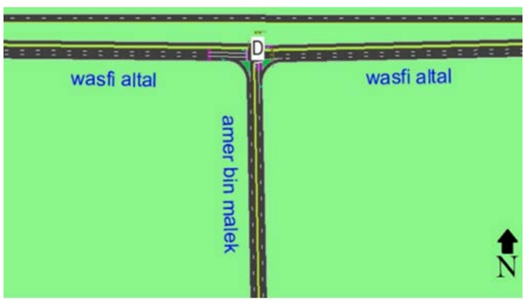

Fig. 14: The LOS at Abu Hdeeb Intersection when use the CGT intersection

Abu Hdeeb intersection. The simulation results showed that the intersection had little improve because of the higher traffic volumes, but in general the average delay decreased from 56.4-39.2 sec and this change of the average delay led to improve the LOS of the main intersection from E to D.The maximum value of v/c ratio is <1 and this means all of these approaches can be accommodated within the current cycle length where the cycle length decreased from 150-90 sec at the main intersection. Through traffic volumes from EB travels without signals controlled so the vehicles do not need to stop at the intersection and the LOS of these two lanes will be A, Fig. 14 and 15 shows the CGT intersection LOS at Abu Hdeeb Intersection.

RESULTS AND DISCUSSION

Table 16-18 shows the comparison between the MOE's that resulted from the simulation at each intersection where at Alaqsa Intersection the optimizing of signals had a negative effective where the delay and v/c ratio increased while the single quadrant alternative decreased the average delay from 56.35-15 s/veh, the intersection delay decreased from 61-23.2 sec and the cycle length decreased from 140-60s, so, the LOS of this intersection improved from E to C.

Table 16: The comparison between MOE's at All Intersections

	Alaqsa intersection			
MOE	current intersection	Optimizing signals	Single quadrant	Jug-handle
Average delay per vehicle (s/veh)	56.35	55.53	15	13.4
Intersection delay (s)	61.3	82.5	23.2	13.4
Cycle length (s)	140	105	60	55
Maximum v/c ratio	0.92	1.1	0.95	0.77
LOS	E	F	C	B

Table 17: Ebad Alrahman intersection

MOE	Current intersection	Optimizing signals	Bow-tie Intersection
Average delay per vehicle (s/veh)	81.4	67.95	18.9
Intersection delay (s)	77	80.3	17.9
Cycle length (s)	175	95	50
Maximum v/c ratio	0.9	1.12	0.9
LOS	E	F	B

Table 18: Abu Hdeeb intersection

MOE	current intersection	Optimizing signals	CGT Intersection
Average delay per vehicle (s/veh)	42.8	53.2	42.1
Intersection delay (s)	56.4	83.5	39.2
Cycle length (s)	150	110	90
Maximum v/c ratio	0.96	1.13	0.93
LOS	E	F	D

The Jug-handle alternative decreased the average delay from 56.35-13.4 s/veh, the intersection delay decreased from 61-13.4 sec, the cycle length decreased from 140-55s and the maximum v/c ratio decreased from 0.92- 0.77, so, the LOS of this intersection improved from E to B and these results led to show that the Jug-handle alternative is better than the other alternatives.

At Ebad Alrahman Intersection the optimizing of signals had a negative effective despite the decreasing in cycle length where the delay increased from 77-80.3 sec and v/c ratio increased from 0.9-1.12 so the LOS changed from E to F. While the Bow-tie alternative decreased the average delay from 81.4-18.9 s/veh, the intersection delay decreased from 77-17.9 sec and the cycle length decreased from 175-50s, so, the LOS of this intersection improved from E to B.

At Abu Hdeeb Intersection the optimizing of signals had a negative effective despite the decreasing in cycle length, where the delay increased from 56.4-83.5 sec and v/c ratio increased from 0.96 -1.13, so, the LOS changed from E to F. While the CGT intersection decreased the average delay from 42.8-42.1 s/veh, the intersection delay decreased from 56.4-39.2 sec, the cycle length decreased from 150-90s and the maximum v/c ratio decreased from 0.96 -0.93, so, the LOS of this intersection improved from E to D.

CONCLUSION

To achieve this research aim the highly congested intersection in Amman, the capital of Jordan was studied, the most suitable UAID alternative were used at each intersection. The base models for each intersection was conducted using Synchro Studio 9 and Simtraffic and run each model 100 times, the duration of each run was one hour to validate the model.

The simulation results showed that the optimizing of the signals have not produced encouraging results for all intersections because the average delay at each intersection and the queue lengths increased which led to deteriorate in LOS.

The implementing of single quadrant intersection at Alaqsa Intersection decreased the average delay at the main intersection from 61.3-22.2 sec, decreased the cycle length from 140-60 sec, the maximum queue length was 135.3 m at NB of through traffic and decreased to be 63.4 m and the LOS improved from E to C.

The implementing of Jug-handle intersection at Alaqsa Intersection has produced better simulation results than Single Quadrant where the average delay decreased from 61.3-13.3 sec, the cycle length decreased from 140-55 sec, the maximum queue length was 135.3m at NB of through traffic and decreased to be 47.3 m and the LOS improved from E to B.

The simulation results of implementing bow-tie intersection at Ebad Alrahman Intersection showed decreased in average delay at the main intersection from 77-17.9 sec, decreased in the cycle length from 175-50 sec and the LOS improved from E to B. The simulation results of implementing the CGT intersection at Abu Hdeeb Intersection showed limited decreased in average delay at the main intersection from 52.5-38.4 sec, the cycle length decreased from 150-90 sec but the LOS did not improve where it was D.

RECOMMENDATIONS

The implementation of the unconventional alternatives on the simulation software showed improvement in the performance in the intersections, but it is not possible to eliminate traffic congestion completely. In addition, to improve the performance the following recommendations are made:

Safety analysis and study the driver's expectations to make sure that these alternatives will be improvable alternatives. Study the congestion problem of the selected areas on a macroscopic level with more field data for accuracy purposes. Study the effect of using the intelligent transportation system to explain the new directions for vehicles that need to make U-turn or left turn.

Using more MOE's to evaluate the performance such as; approach delay and number of stops per vehicle. Raising awareness of the drivers of the importance of using the unconventional intersections and their usefulness to all in improving the efficiency of intersections. Study the effect of using the previous alternatives in the future to know if these are suitable alternatives. Suggest other solutions for Abu Hdeeb Intersection to improve it such as; grade separated solutions, single quadrant and jug-handle. Study the environmental impact of the surrounding area when using some of the local streets. Study the feasibility of these alternatives with more details and try to apply them if the cost estimation is more economical.

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