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Effect of Signal Coordination on The Traffic Operation of Urban Corridor

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Abstract: The severity of traffic congestion has increased in Baghdad city and influenced the public's perception of the community. Extended travel time is experienced by users of the urban street system, so optimal traffic operation with a coordinated traffic signal system becomes necessary. Also, it is needed to alleviate congestion and progress traffic movement along the urban corridor. This study aims to evaluate and optimize traffic signal timing for selected intersections on Palestine arterial corridor and apply the coordinated signal system to reduce the users' travel time on the selected urban corridor. Analyzing and evaluating congested signalized intersections using Synchro (ver.9) (Al-Nakhala intersection, Al-Sakhra intersection, and Beirut intersection) were performed. Also, their adopted strategies for improving traffic performance and reducing delays were provided. The overall assessment in terms of the level of service for the current traffic states is (LOS F) with an average control delay of (197.2, 166.8, and 262.3) sec/veh. for the Al-Nakhala, Al-Sakhra, and Beirut intersections respectively. The queue length appears after two cycles, becoming more severe congestion at intersections under oversaturated traffic conditions. The performance operation efficiency improved by reducing the control delay from (197.2 to 88) sec/veh, (166.8 to 46) sec/veh, and (262.3 to 76) sec/veh for the Al-Nakhala, Al-Sakhra, and Beirut intersections respectively. Even at high volume and oversaturated conditions, the blocked intersections were effectively alleviated. Finally, it was observed that the proposed signal coordination, built on standard actuated control significantly performed along the urban corridor, reducing vehicles' delay. However, there are still concerns regarding the flow-to-capacity ratio (v/c ratio is still greater than 1), and the level of service is still in poor conditions (LOS E) for Beirut and (LOS F) for Al-Nakhala intersections. The application of signal coordination improved traffic progression by reducing travel time, and vehicle delay and alleviating blocked intersections.

تأثير تنسيق الإشارات على التشغيل المروري لممر حضري

زينب أحمد القيسي قسم الطرق والنقل / كلية الهندسة / الجامعة المستنصرية / بغداد - العراق.

الخلاصة

زاد التأثير السيء للزحام المروري في مدينة بغداد على المجتمع، وزيادة أطوال الأميال للنقل وزمن الرحلة لذا فإن التشغيل المروري للإشارات الضوئية المنسقة أصبح ضروريا" لتقليل الزحام وإحراز التقدم في الحركة المرورية على طول الممر الحضري. تحليل وتقييم التقاطعات ذات الإشارات الضوئية المزدحمة (تقاطع النخلة، تقاطع الصخرة، تقاطع بيروت) باستخدام برنامج SYNCHRO الإصدار التاسع. أيضا يتم اعتماد إستراتيجياتهم لتحسين الأداء المروري وتقليل زمن التأخير. أن التقييم الكلي لمستوى الخدمة لحالات المروري الحالية هو مستوى الخدمة (F) مع معدل زمن تأخير التحكم (197.2 ،3.8، 262.166) ثانية/مركبة لتقاطع النخلة والصخرة وبيروت على التوالي. أظهرت النتائج طول طابور بعد دورتيين مما يؤدي الى زحام أكثر تدهورا" عند التقاطعات تحت تأثير الظروف المشبعة. تم تحسين الأداء للتشغيل المروري من خلال تقليل زمن تأخير التحكم من (197.2 الى 88) ثانية/مركبة، و(166.2 الى 46) ثانية/مركبة، (262.3 الى 76) ثانية /مركبة لتقاطع النخلة والصخرة وبيروت على التوالي. على الرغم من الحجم الكبير والظروف المشبعة، الا أنها خففت بشكل فعال من الانسداد في التقاطعات المرورية. أخيرا"، لوحظ أن تنسيق الإشارة المقترح والمبني على التوقيت المتغير له أداء فعال على طول الممر الحضري، والذي بدوره يقلل من تأخير المركبة ولكنه لايزال يتعلق بنسبة التدفق الى السعة الاستيعابية (نسبة v/c لاتزال أكبر من 1) ومستوى الخدمة لايزال في حالة سيئة (مستوى الخدمة E) لتقاطع بيروت و (مستوى الخدمة F) لتقاطع النخلة. أدى تطبيق تنسيق الإشارات الضوئية الى تحسين تقدم التشغيل المروري من خلال تقليل التأخير للمركبات وتقليل زمن الرحلة وتخفيف حدة الزحام في التقاطعات المسدودة.

الكلمات الدالة: تنسيق الأشارة، ممر حضري، التقاطعات ذات الإشارة الضوئية، التشغيل المروري، سنكرو، زمن الرحلة، التأخير.

1.INTRODUCTION

The traffic signal coordination benefit is based on the relationship between signalized intersections. The traffic speed along an urban corridor depends on the signal spacing and the cycle length at traffic signals. The platoon's speeds are reduced when traffic signals are closely spaced and operate under a short cycle length. Several studies explore the usage of the Quadrant Roadway Intersection (QRI) for different configurations of intersection and reported a reduction in travel time during peak and nonpeak conditions [1]. The Federal Highway Administration (FHWA) classified microsimulation and macroscopic simulation models for vehicle movements to assess traffic operation. They simulated each vehicle's characteristics and interactions with other traffic stream components to provide valuable data about the existing system's performance [2]. The SYNCHRO software is a microscopic analysis level. Also, it is a signal optimization software. It is based on the highway capacity manual, the methodology for traffic operation of signalized intersections, and applies the intersection capacity utilization (ICU) method to determine intersection capacity [3]. Also, SYNCHRO estimates the measure of effectiveness (MOE) for each lane, approach, intersection, and the whole network [4]. Studies upgraded the travel time distribution using the MAX BAND model by analyzing the discrete phenomenon of vehicles under the oversaturated condition to get the optimal parameters of traffic signal coordination [5], [6]. The effect of coordination on safety using a novel multi-nominal logit model was investigated, and it was found that the crash probability can be estimated, and it was stated that the minimum cycle lengths were related to a lower risk of crashes [7]. An improved graphical method and estimated queue length using a vehicle queuing accumulation curve were applied to control the spillover of queues along the arterials with signalized intersections of oversaturated conditions [8]. Connected autonomous vehicles (CAVs) are not suitable to consider as means of increasing road capacity [9]. Thus, connected autonomous vehicles could provide a new traffic data management source and be used as actuators in traffic flow [10]. Analyzation and implementation of a continuous flow of intersections in Amman named Tabarbour using field data were utilized. Microsimulation software VISSIM and SYNCHRO were utilized to model and compare the conventional conditions with an improved strategy [11]. A reduction of 97% and 87% for maximum queue and average vehicle delay were obtained and, the level of service was improved from F to C. The effect of the signal coordination system on driving characteristics was explored. It was found that the implementation of signal coordination made younger, male, and pick–up drivers more responsive to crash accidents. Also, aggressive driving behaviors appeared in a coordinated system more than in non-coordinated corridors [12]. The speed for mixed traffic flow was higher than the critical speed, and the stability of the mixed traffic flow was reduced with a high penetration rate [13]. Implementation of displaced left turn (DLT) intersections reduced the extra stops of vehicles and improved the overall efficiency of a signalized intersection.

The reduction in the queue length ranged from 47.5 to 42%; otherwise conventional intersections showed long queue lengths and higher vehicle delays. Therefore, regarding the queue length, DLT intersections with developed signal timings strategy had better traffic operation performance than a conventional intersection [14]. The dynamic changes in traffic demand throughout the day and year induced traffic overload. These characteristics made it challenging to implement green wave coordinated control and provide acceptable effects [15]. A signal optimization method on congested areas was proposed to estimate the maximum throughput of the road network in oversaturated conditions. The density wave transfer velocity was utilized throughout an estimation model based on a 3D macroscopic fundamental graph model to assess the congested downstream region and determine the control boundary, and dynamic changes [16, 17]. The green wave coordinated control theory was investigated, and the strategy was expanded to different roadways and conditions. The coordinated control methods for urban streets were classified into two categories: the optimization of green wave bandwidth and the optimization of other measures of effectiveness such as minimum delay time, stops, and queue length [18, 19]. Urban cities suffer from the explosive growth in vehicular traffic volume on major arterials, and a steady increase in traffic jams, vehicle mileage, and travel time was detected. Hence providing optimal traffic operations was the ability of network designs with coordinated traffic signal systems to alleviate congestion and to progress traffic movement along major urban corridors. This research analyzed and compared traffic operation along a typical arterial street under conventional conditions and adopted strategies to improve traffic performance and reduce delays for three signalized intersections along an arterial corridor. The previous studies indicated that a traffic signal coordination system helped reduce delays which will be helpful for traffic operation. However, most methods adopted in the literature still need to adopt the change in traffic regulation for local regions' laws. The objective of this research is to study and optimize the traffic signal timing for selected intersections on Palestine arterial corridor and its contribution to a coordinated signal system to reduce the travel time for users on the street network.

2.METHODOLOGY

2.1.Case Study

The proposed methodology analyzed the signalized intersections (Al- Nakhala, Al-Sakhara, and Beirut) along the corridor of Palestine urban street. Fig. 1 shows the digitized map of the urban region with selected signalized intersections (including major Palestine Street with secondary roads). The case study map is bounded by the spatial extension 33° 22' 30'' N to 33° 21' 0'' N and 44° 24' 30'' E to 44° 25' 30'' E. The accomplishment of the research objective requires the following steps of methodology, proposed strategies analysis, and evaluation of signalized intersections along the urban corridor:

- Identified the most congested signalized intersections (Al-Nakhala, Al-Sakhara, and Beirut) along the corridor of Palestine urban street based on previous studies for the study area, [20, 21].
- Analyzing and evaluating congested signalized intersections using Synchro (ver.9) and SimTraffic ware software, estimating volume to capacity ratio (v/c), control delay per vehicle, and determining the corresponding level of service (LOS) based on Highway Capacity Manual (HCM, 2000) methodology.

Improvement techniques using arterial signal coordination for adaptive signal system. Estimate offsets based on the actual travel speed of major streets measured in the field with forecast correction [22].

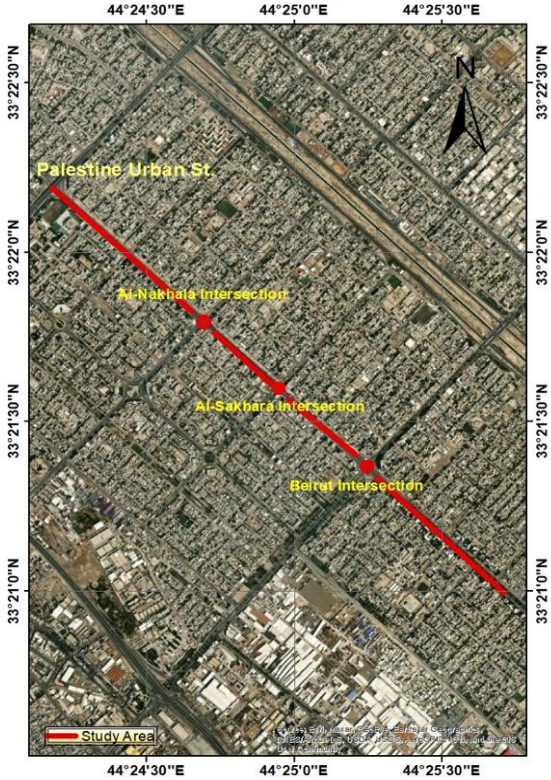


Fig.1 The Digitized Map of the Study Area.

2.2.Data Collection

The study area of this research included Palestine urban corridor with three signalized intersections (Al- Nakhala, Al-Sakhara, and Beirut), as depicted in Fig. 1. These signalized intersections suffer from current daily congestion during peak periods. The investigated roads spread from Palestine urban street along its corridor from the Al-Mawal intersection to Beirut Intersection with major urban and collector roads. Reconnaissance survey; floating car method (for collecting volume) with the global positioning system GPS technique was utilized as the primary source of data collection. The collected field data could measure the traffic operation of studied signalized intersections during the peak periods from (11:00 a.m. to 5:00 p.m.) on 11, 12, and 13 April 2022 and 23, 24, and 25 May 2022. April and May, as spring months, were chosen due to the high traffic flow distribution in the study area. The traffic volume data based on 15 min. intervals are shown in Figs. (2-4) for Al-Nakhala, Al-Sakhara, and Beirut signalized intersections respectively. The traffic volume data were recorded based on a 15-minute interval and summed up into one-hour intervals. It was observed that the period (2:00 p.m. -4:00 p.m.) had the peak traffic volume for the Al-Nakhala intersection of (4600 veh/hr), and the peak period (1:00 p.m. -3.00 p.m.) with peak traffic volume for Al-Sakhara intersection of (4100 veh/hr). Finally, the Beirut intersection induced the highest traffic volume of (5088 veh/hr) from (1:15 p.m. to 3:15 p.m.). The distribution of hourly traffic volume depicted that some intersections approaches had obvious peak periods that included through traffic (north-south directions) along Palestine Street, while other approaches had significant precise peak hours, and this was obvious from the peak hour factor results for the intersection approaches as presented in Figs. (5-7) for Al-Nakhala, Al-Sakhara, and Beirut respectively. For more clarity and illustration, a schematic map of the study area illustrating the spatial distribution of peak-hour traffic volumes is shown in Fig. 8.

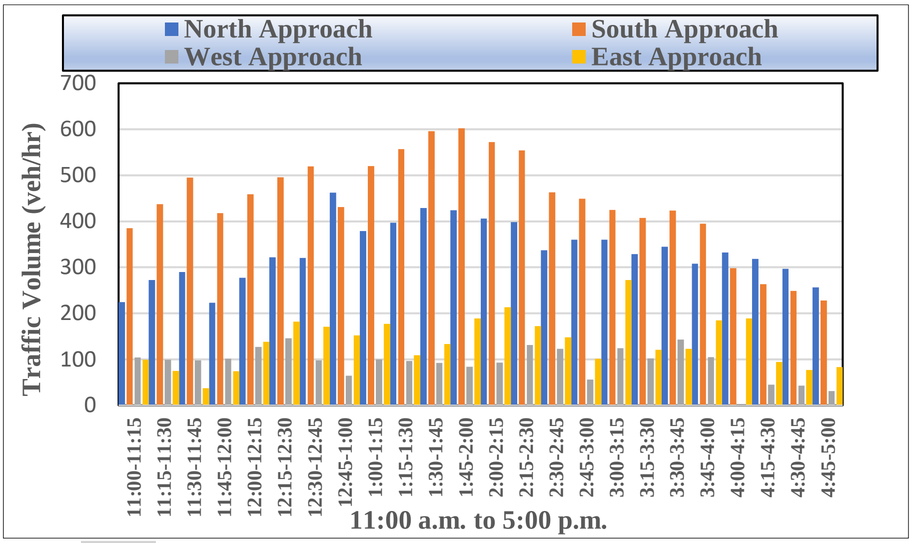


Fig. 2 Field Data of Traffic Volume for Al-Nakhala Intersection.

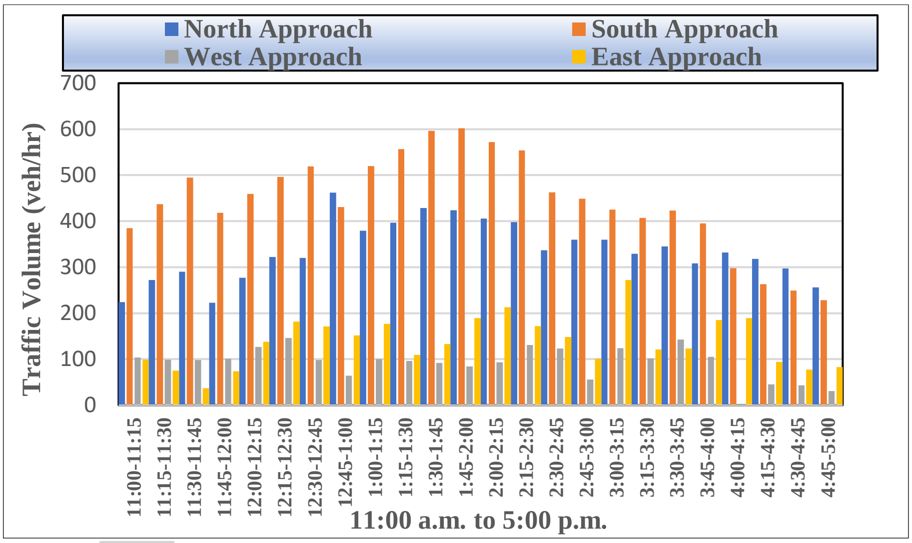


Fig. 3 Field Data of Traffic Volume for Sakhara Intersection.

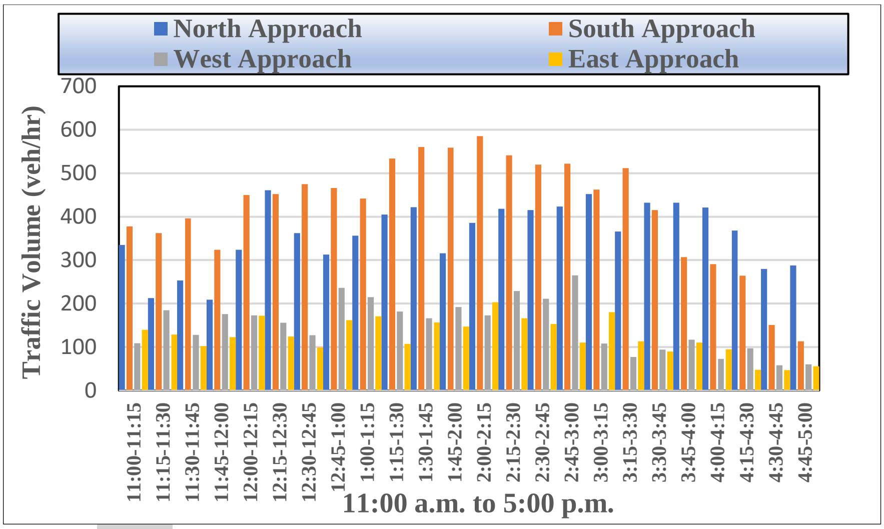


Fig. 4 Field Data of Traffic Volume for Beirut Intersection.

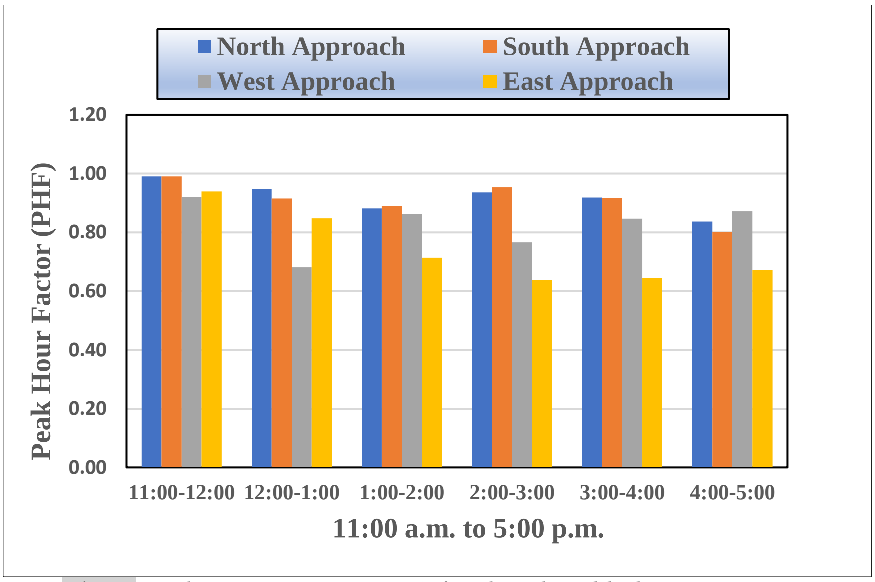


Fig. 5 Peak Hour Factor (PHF) for the Al-Nakhala Intersection.

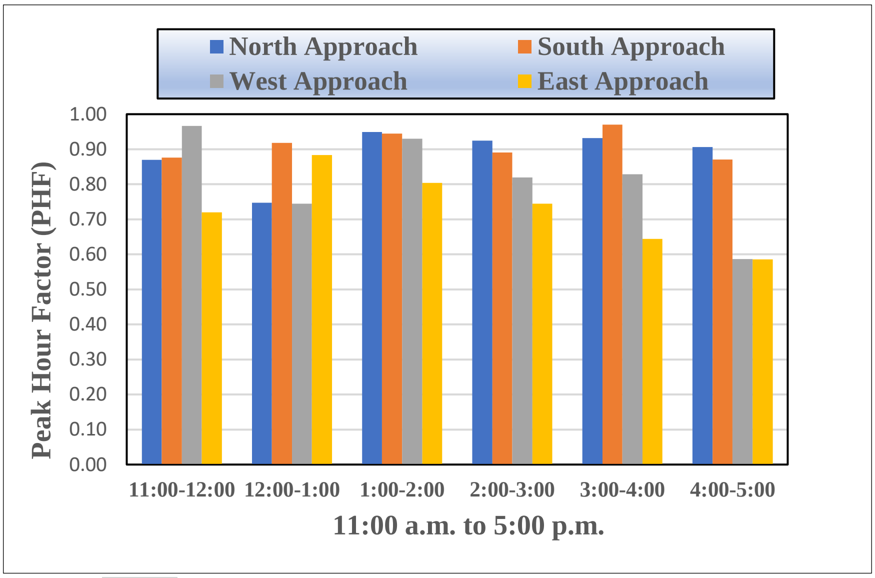


Fig. 6 Peak Hour Factor (PHF) for Sakhara Intersection.

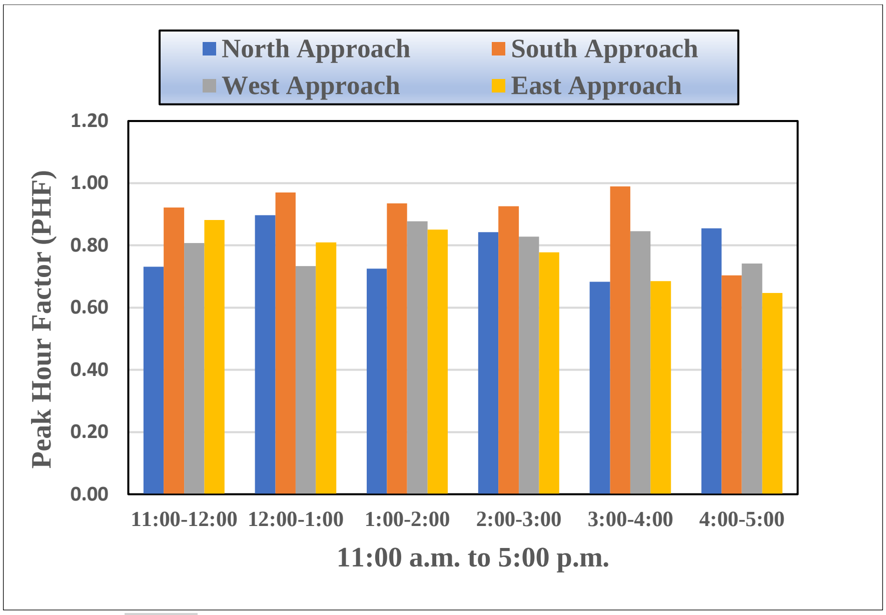


Fig. 7 Peak Hour Factor (PHF) for Beirut Intersection

Fig. 8 Schematic Map of Traffic Volume in (Veh/Hr) Variation of the Case Study.

3.RESULTS AND DISCUSSION

This study explored the traffic operation of Palestine Street with signalized intersections as a case study. Several analysis and simulation models using Synchro ver.9 were implemented to represent the actual traffic operation of signalized intersections (Al-Nakhala intersection, Al-Sakhra intersection, and Beirut intersection). Also, their adopted strategies for improving traffic performance and reducing delays were provided.

3.1.Analysis of Base Model for Actual Condition

The analysis of the studied intersections using Synchro simulated the actual situations. Generally, in Baghdad city, most signalized intersections have been controlled by a policeman from arbitrary judgment for timing depending on maximum serving flow and four phases split (phase for approach movements). Based on that, actuated signal timing system was adopted to simulate the intersection signals by Synchro using maximum green time for actual green. All the data required for analysis were obtained from the field as described previously. The three studied signalized intersections along the corridor of Palestine Street were drawn using Synchro (ver.9) software with input data for volume and timing signals as shown in Figs. (9-12). The results' reports are presented in Figs. (13-15) for Al-Nakhala, Al-Sakhra, and, Beirut intersections, respectively. The traffic operations of all studied signalized intersections were poor and induced oversaturation conditions due to high traffic demand. The overall assessment in terms of the level of service for the current condition was (LOS F) with an average control delay of (197.2, 166.8, and 262.3) sec/veh. For Al-Nakhala, Al-Sakhra, and Beirut intersections respectively. The queue length appeared after two cycles which caused more severe congestion at intersections under oversaturated traffic conditions.

3.2.Improvement using Signal Coordination

The traffic congestions during the peak hours of selected signalized intersections are more severe as discussed in the previous section. Traffic signal synchronization using signal coordination control was implemented to provide minimum stopping delays and reduce travel times. Palestine Street as an arterial with a high carrying traffic volume over a long distance in the study area, was the main object of the traffic coordination system to alleviate congestion and promote the operation efficiency of signalized intersections. Arterial coordination control was adopted using optimum offsets to allow continuous flow through signalized intersections. The set of signals for Al-Sakhra and Beirut intersections was set to run on the same cycle length. Synchro contains several optimization types, offsets, and phase splits to reduce the number of stops and delays. The optimization types were applied to the studied intersections within the urban corridor as presented in Figs. (16, 17). A comparison of delay results for signal coordination with offset optimization is shown in Fig. 18. The performance operation efficiency improved by reducing the control delay from (197.2 to 88) sec/veh., (166.8 to 46) sec/veh., and (262.3 to 76) sec/veh. for Al-Nakhala, Al-Sakhra, and, Beirut intersections, respectively. However, the flow-to-capacity ratio (v/c ratio was still greater than 1), and the level of service was still in poor conditions (LOS E) for the Beirut intersection and (LOS F) for the Al-Nakhala intersection. The simulation analysis results indicated that signal coordination reduced control delay per vehicle, even at high volume and oversaturated conditions, and effectively alleviated the blocked intersections. Figs. (19, 20) illustrate the Synchro flow diagram to show how the offsets affect traffic flow. It is clear that traffic flow evenly arrived at the Al-Nakhala intersection. Also, vehicle accumulation was initiated during the red interval to form a triangle (representing the developed queue length). After the green phase had started for the main street, vehicles departed, and the oblique lines depict the vehicle trajectory. The arterial signal coordination provided progression through traffic and reduced traffic congestion and the developed queue length. Offsets were estimated based on the actual travel speed of major streets as shown in Fig. 20, providing progression and allowing vehicle discharge before the heavy platoon arrives. Overall, the results showed that the proposed signal coordination built on standard actuated control had an efficient performance along the urban corridor, reducing vehicle delay.

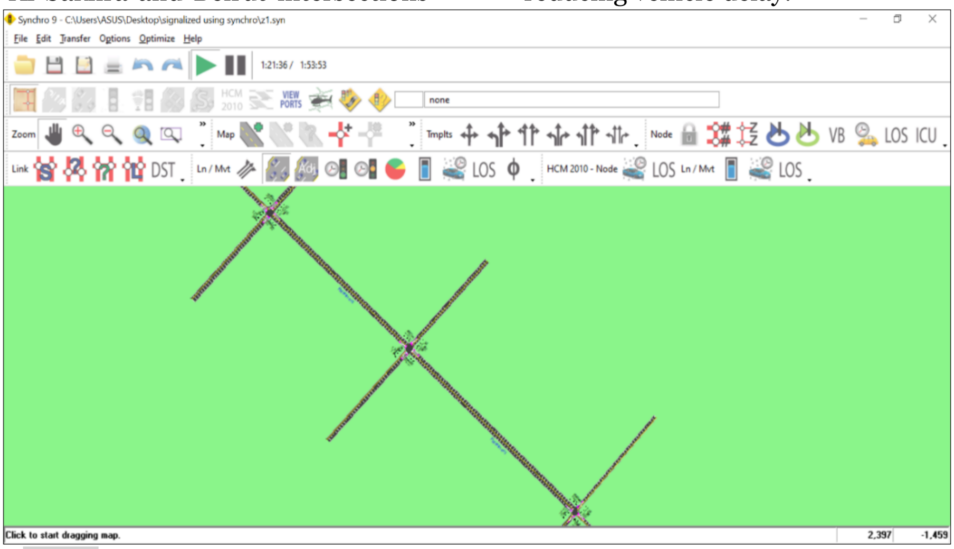


Fig. 9 The Studied Signalized Intersections Along the Corridor using Synchro Software.

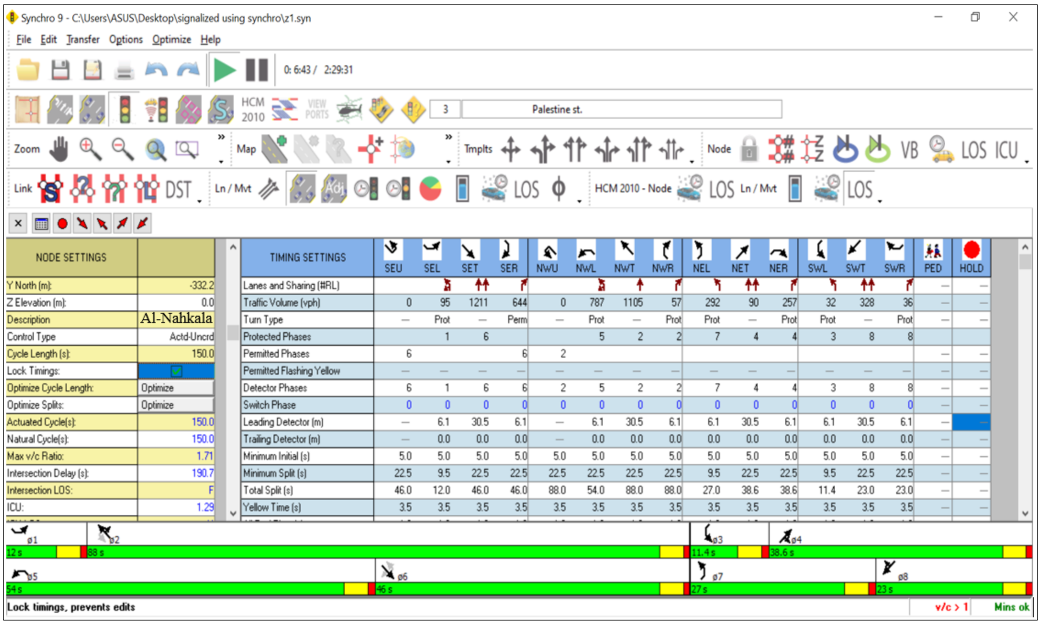


Fig. 10 Input Data for Analysis using Synchro for the Al-Nakhala Intersection.

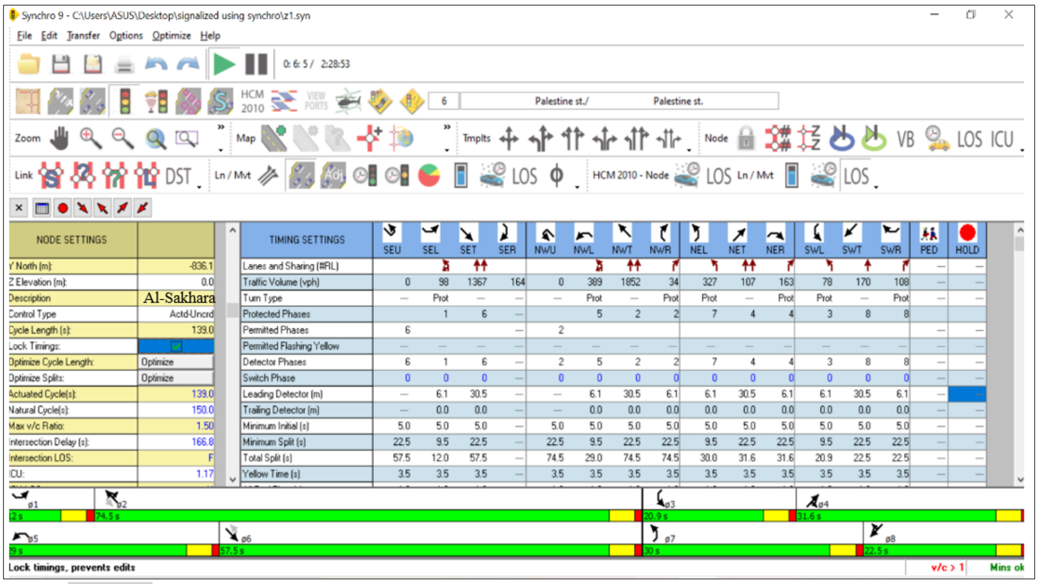


Fig. 11 Input Data for Analysis using Synchro for the Al-Sakhra Intersection.

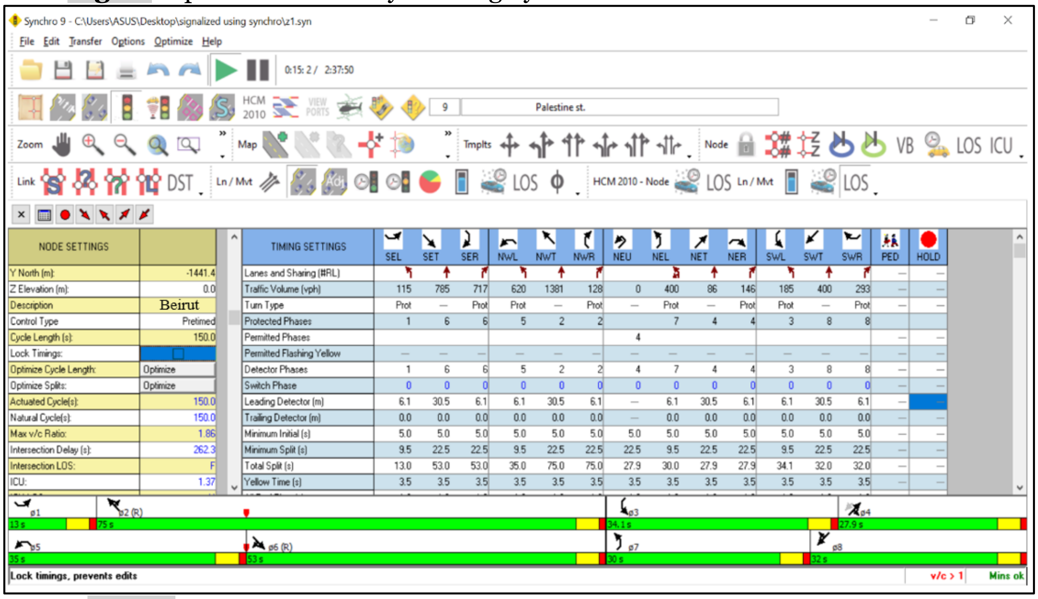
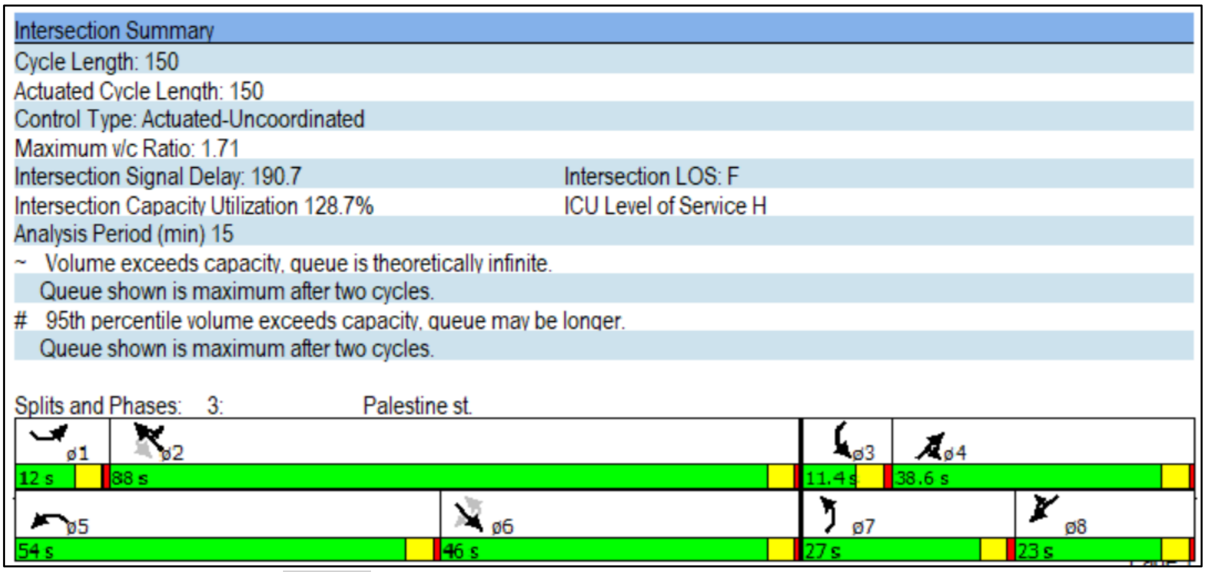


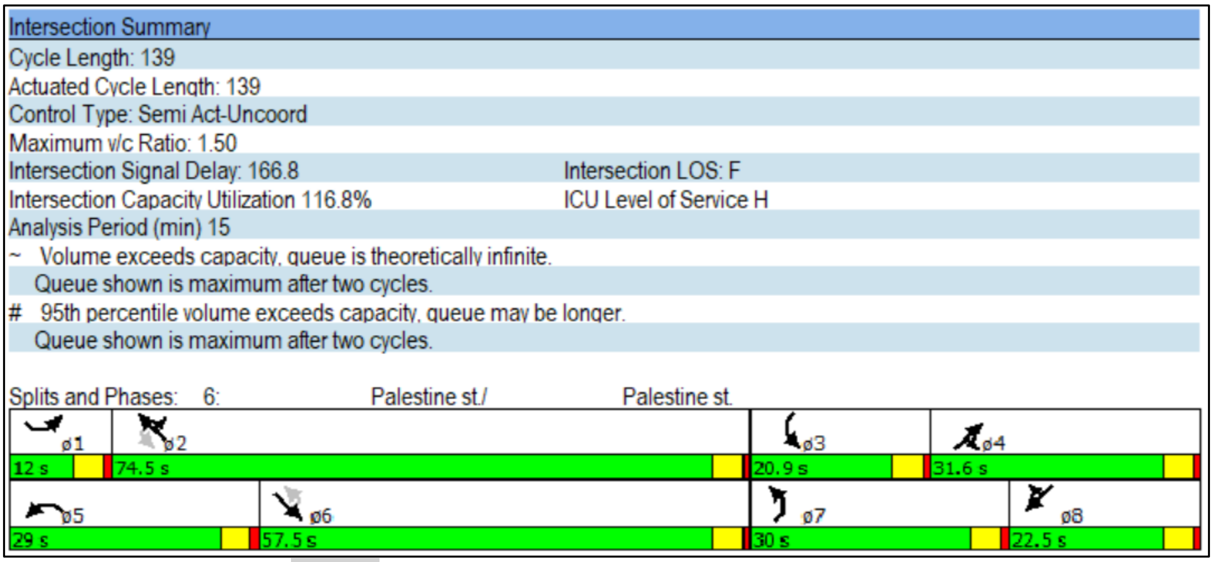
Fig. 12 Input Data for Analysis using Synchro for the Beirut Intersection.



Intersection Summary
Cycle Length: 150
Actuated Cycle Length: 150
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 1.71
Intersection Signal Delay: 190.7 Intersection LOS: F
Intersection Capacity Utilization 128.7% ICU Level of Service H
Analysis Period (min) 15
~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 3: Palestine st

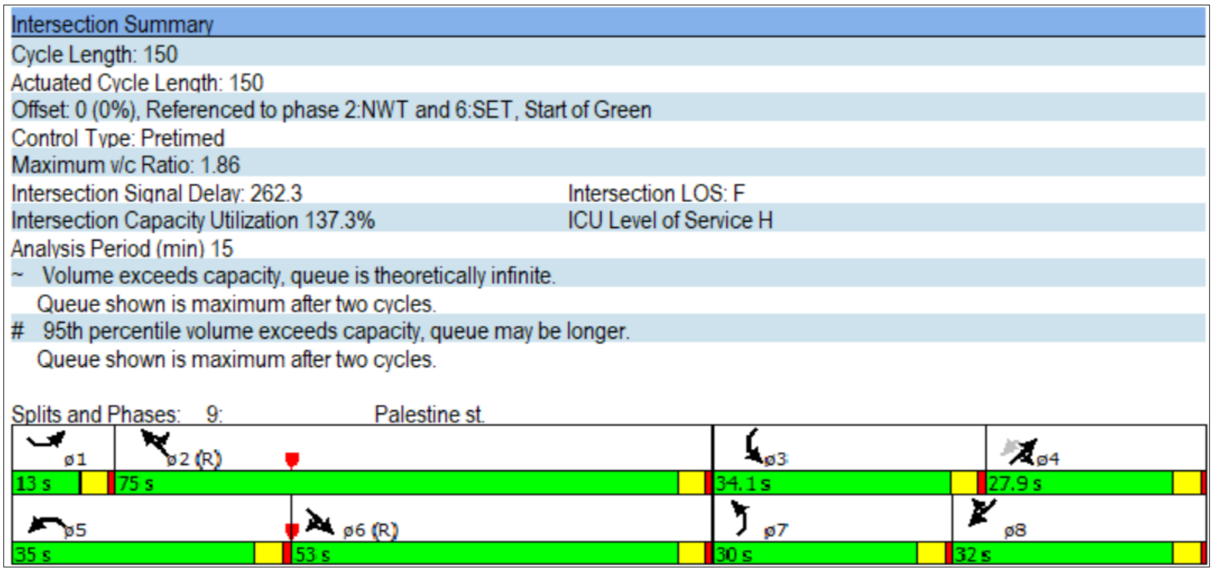
Fig. 13 Results Summary for Al-Nakhala Intersection.



Intersection Summary
Cycle Length: 139
Actuated Cycle Length: 139
Control Type: Semi Act-Uncoord
Maximum v/c Ratio: 1.50
Intersection Signal Delay: 166.8 Intersection LOS: F
Intersection Capacity Utilization 116.8% ICU Level of Service H
Analysis Period (min) 15
~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 6: Palestine st/ Palestine st

Fig. 14 Results Summary for Al-Sakhra Intersection.



Intersection Summary
Cycle Length: 150
Actuated Cycle Length: 150
Offset: 0 (0%), Referenced to phase 2:NWT and 6:SET, Start of Green
Control Type: Pretimed
Maximum v/c Ratio: 1.86
Intersection Signal Delay: 262.3 Intersection LOS: F
Intersection Capacity Utilization 137.3% ICU Level of Service H
Analysis Period (min) 15
~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 9: Palestine st

Fig. 15 Results Summary for Beirut Intersection.

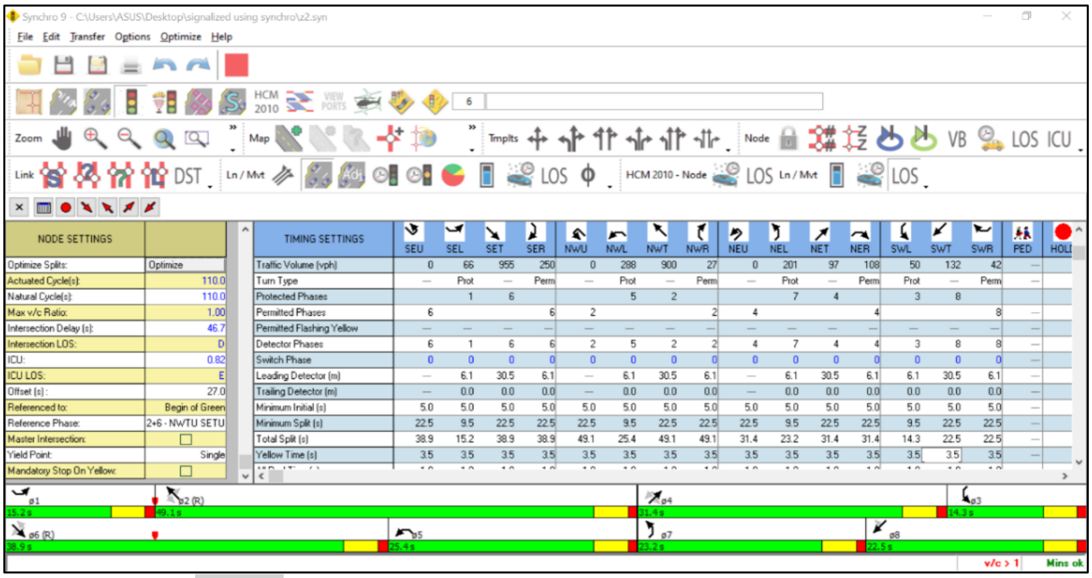


Fig. 16 Offsets and Phase Split for Al-Sakhara Intersection.

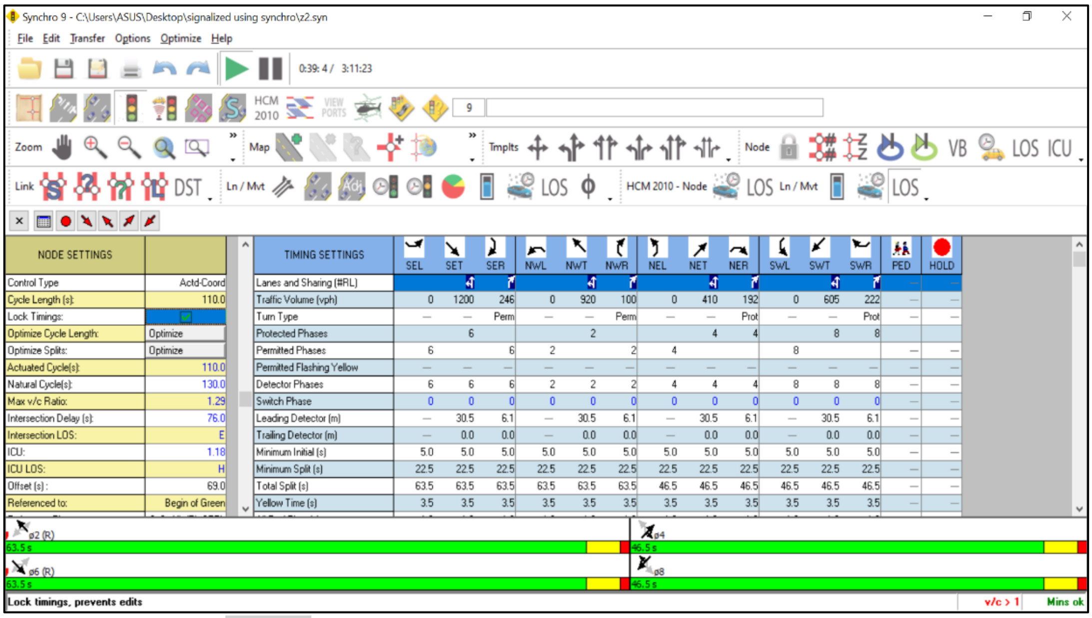


Fig. 17 Offsets and Phase Split for Beirut Intersection.

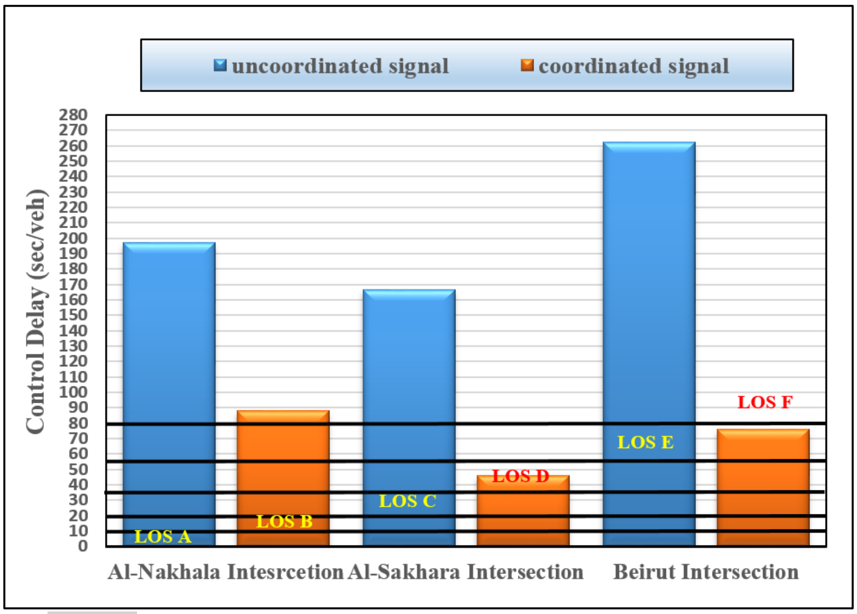


Fig. 18 Comparison of Control Delay at Signalized Intersections.

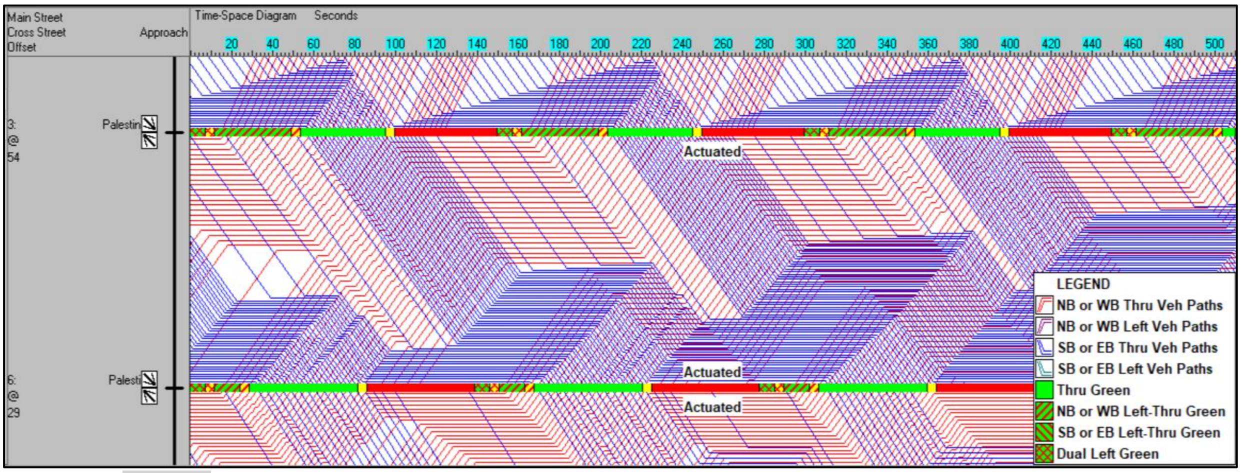


Fig. 19 Space-Time Diagram for Actual Traffic Flow Along Palestine Arterial Street.

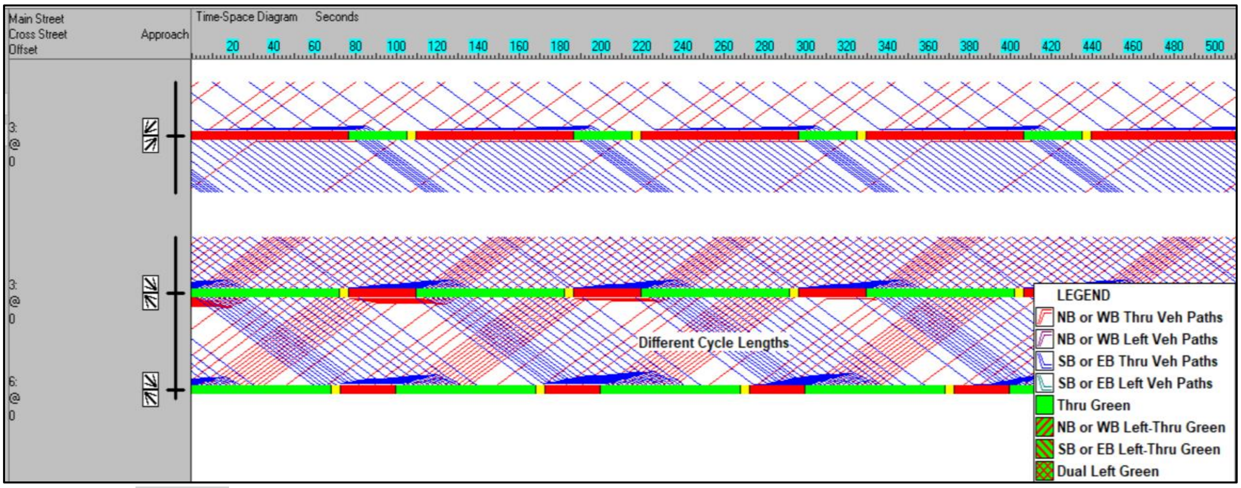


Fig. 20 Space-Time Diagram for Traffic Flow Along Palestine Arterial Street After Signal Coordination.

4.CONCLUSIONS

This section illustrated the main finding of this research as follows:

1. The traffic operations of all studied signalized intersections were poor and induced oversaturation conditions due to high traffic demand.
2. The overall assessment in terms of the service level for the current traffic states was (LOS F) with an average control delay of (197.2, 166.8, and 262.3) sec/veh. for Al-Nakhala, Al-Sakhra, and, Beirut intersections respectively.
3. The queue length appeared after two cycles which caused more severe congestion at intersections under oversaturated traffic conditions.
4. Another significant finding was that signal coordination reduced control delay per vehicle, even at high volume and oversaturated conditions, and effectively alleviated the blocked intersections.

Finally, the obtained results showed that the proposed signal coordination, built on standard actuated control, had an efficient performance along the urban corridor, which in turn reduced vehicle delay yet still concerned the flow-to-capacity ratio (v/c ratio was still greater than 1). Also, the level of service was still in poor conditions (LOS E) for Beirut intersection and (LOS F) for the Al-Nakhala intersection.

RECOMMENDATION

The application of signal coordination improved traffic progression by reducing travel time, and vehicle delay and alleviated blocked intersections.

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