Application and Suitability of Signal Coordination

UNEB GAZDER
Civil Engineering
University of Bahrain
Sakhir, 32038
BAHRAIN

Abstract: - The aim of this study was to apply signal coordination for eight signalized intersections in three different locations and compare the performance before and after the adjustments. To achieve the above objective, we collected traffic data from the sites and from the ministry of works. VISSIM software was used for evaluation and analysis of intersections. SYNCHRO software was used for finding the best timing plan alongside manual solution (trial-and-error). We got a high delay and bad level of service for all of the selected intersections before applying the signal coordination. Then the improvement strategy of optimizing signal timing and coordination was applied to the traffic flow in the study areas. Finally, this improvement was found to have good effect on the level of service and delays, where we reduced the delay in all the locations by approximately 34% and improved the level of surface from F to E on Estiqlal highway and 16th December Highway and from D to C on Tubli highway. The strategies and design from this research can be implemented on the selected locations and serves as a benchmark for other similar studies in the region.

Key-Words: - Bahrain; Intersections; Signals; Level of service; Timing; Level of Service

Received: April 11, 2023. Revised: October 21, 2024. Accepted: November 15, 2024. Published: December 12, 2024.

1 Introduction

In situations where traffic signals are close to each other, so that vehicles arrive at the downstream intersection in platoons, it is necessary to coordinate their green times so that vehicles may move efficiently through the set of traffic signals without the need to have drivers stopping at all the signals. Bahrain is facing rapid increase in vehicle registration. Consequently, traffic congestion and delay has been also increasing, more so, at the closely spaced intersections. Design of coordinated signals is one of the approaches to mitigate the effects of congestion. To this effect, our study aimed to design coordinated signals at important highways in Bahrain.

2 Literature Review

Signal Coordination is basically timing a set of traffic signals along a major roadway to provide smooth flow and minimal stops [1]. We need signal coordination to make mobility as efficient as possible between intersections, and this technique will make us dispense roadway widening [2]. It will minimize the percentage of accidents; on the other hand, it will increase in travel speed which may have a negative impact in the community [3].

Offset is the difference between two green initiation times. The ideal time of offset is the time needed by the vehicles to move from one intersection to another (distance/Speed); unless, when there is a queue in the downstream intersection which will make the coming platoon reduce speed and maybe stop which we are trying to avoid. So, we have to adjust the offset by adding some factors, as shown in equation 1 [4].

$$t_{adjusted} = 3600 \times \frac{L}{S} - (Qh + l_1) \quad (1)$$

$\boldsymbol{t_{adjusted}}$= adjusted ideal offset, s
L= distance between signals, km
S= Speed, kph
Q= Number of vehicles
h= Discharge headway of queued vehicles, s/veh.
$\boldsymbol{l_1}$= Start-up lost time at first downstream intersection, s

Over Saturated Flow happens when demand exceeds capacity. Because of that, unstable queue will keep on increasing until it reaches the spillback point. Therefore, it will block the upstream intersection (Reducing capacity). In our project all of our locations are suffering from oversaturated flow

which makes signal coordination needs more effective solutions.
The management of traffic in oversaturated conditions will be slightly different and the priority will be avoiding queue spillbacks, avoiding saturation and managing queue formation. There are many reasons for the intersections to be over-saturated (demand exceeds the capacity). Some of them are as follows: Convergence of routes (when there are lots of routes connecting in small area), Two major roads crossing each other (each have high traffic and will lead to definite delay to one of them or both) or Seasons and events (like sports day or national day or rainy days) [5].
For over saturated intersections there are two main approaches to solve the over-saturation: throughput strategies (which are considered curative) and queue management strategies (which are considered palliative). Throughputs strategies are used to remove the long queue and solve the problem permanently (Find and use the right cycle, Service heavy movements more than once in a cycle and seek all possible available green time). Sometimes the throughput strategies may not work the way traffic engineer wants, so we can use queue management strategies to help stop the queue increasing in an unstable way (Balance the queues for conflicting approaches, prevent queues from spreading congestion) [6].
Signal coordination strategies have been reported to help with various aspects of traffic, apart from improving traffic flow. In this regard De Coensel et al. [7] have reported their positive impact on noise and air pollution mitigation. Moreover, Zhang et al. [8] have reported the positive impacts on signal coordination reducing crash risks. In the same context, studies have also reported an increase in proportion of severe crashes due to signal coordination [9].
There is a lacking in the literature related to studying effects of signal coordination in Gulf region, especially for Bahrain. Moreover, the evaluation of the contextual scenarios in which signal coordination could perform better is also missing. These gaps are being filled by the current study.

3 Study Locations and Signal Coordination Approaches

3.1 Study Locations

We have three study areas; each area located in a different position as explained below.

Esteqlal Highway starts from Bahrain Polytechnique to Baghdad - Esteqlal junction, (26°10'7.13"N, 50°32'37.94"E), and shown in Fig. 1

Fig. 1. Esteqlal Highway Intersections Location

It consists of two junctions affecting each other, and in peak hours these junctions get over-saturated especially when the students are leaving or entering the educational area. The queue starts from intersection 2 and goes to intersection 1 and keep increasing and blocking the intersections resulting in high delay.

16 December starts from Indian school to Sh. Salman Hwy & Sh. Zayed Hwy junction, (26° 9'25.80"N, 50°32'19.65"E), and shown in Fig. 2.

Fig. 2. 16th December Highway Intersections Location

These two junctions affect each other and in peak hours these junctions (intersections) get oversaturated creating unstable queue that increase with time and block the upstream intersection (intersection 1)
Tubli highway starts from Bahrain Map Monument to Wastewater Treatment Station, (26°12'12.47"N,50°34'1.07"E),(26°11'52.55"N,50°33'28.80"E), and shown in Fig. 3.

Fig. 3. Tubli Intersections

In this location, there are four junctions consequently, starting from Bahrain Map Monument junction and ending up with waste-water treatment plant junction. Moreover, the distance between first junction 1 and junction 2 is approximately 280 m, while the distance between junction 3 and junction 4 is roughly 425 m. In this study location the queue is forming alongside the main street in both directions.

3.2 Signal Coordination Approaches

This study deals with locations which have over saturated flow conditions. Over saturated flow happens when demand exceeds capacity. Because of that, unstable queue will keep on increasing until it reaches the spillback point. Therefore, it will block the upstream intersection (Reducing capacity). The management of traffic in oversaturated conditions will be slightly different and the priorities are set to avoid queue spillback and saturation, managing queue formation and providing equitable service [5].

3.3 Approaches to Address Over-Saturation:

For over saturated intersections there are two main approaches to solve the over-saturation, Throughput strategies (which it considered curative), Queue management strategies (which it considered palliative) [10]. Sometimes the throughput strategies may not work the way traffic engineer wants, so we will use queue management strategies to help stop the queue increasing in an unstable way [11].
It is difficult to exaggerate how often the basic problem is poor signalization. Once the signalization is improved through shorter cycle lengths, proper offsets and proper splits, the problem may disappear. Or maybe the problem is too much traffic where we will use the concept of phase re-service to manage the spread of congestion. These two options may be used as distinct treatment or as part of a metering plan (as mentioned earlier).
For intersections located along arterial streets, isolated operation can often be improved by considering coordination of the major street movements along the arterial. Common cycle lengths are often employed to facilitate this coordination. It is not necessary that when cycle length increases, the intersection capacity will increase. But it is important to discharge the queue in which case shorter cycle length will be better which could be estimated from Equation 2.

$$C \leq (L/D)(3600/v_i) \qquad (2)$$

C = Cycle length, sec.
L = Length of downstream link in a congested environment, ft.
D = storage space per vehicle, ft.
vi = The discharge volume per downstream lane (critical flow – veh/hr/lane).
Note that 'D' equals approximately 25 feet, and 'L' taken as 85% of its origin value to keep queue away of discharging intersection (assuming that the downstream link can itself discharge the arriving queue in one cycle) [10].
The spacing of signalized intersections 'L' affects how one times the signals. For signals that are sufficiently far apart that they can be considered independent of one another, intersections may be operated freely without need for or benefit from coordination, depending on the degree of congestion on the facility. For most arterial streets with signal spacing between 500 feet and 0.5 mile (2,640 feet), coordinated operation can often yield benefits by improving progression between signals. On arterials with higher speeds, it can be beneficial to coordinate signals spaced a mile (5,280 feet) apart or even longer. Signals that are located very close together (less than 500 feet) often require settings that manage queues, rather than progression, as the dominant policy. It may also be beneficial to operate two intersections with very close spacing with a single controller.

4. Data

Some of the geometric data has been collected from the field, for e.g., the number of lanes and their approaches. The traffic volume data was collected from the roads department in the Ministry of Works (for each intersection at all hours). The peak hours for traffic data collection are determined from the acquired data. Speed measurement was carried out in the field by measuring the time taken by vehicles to pass trap length. We took the speed of 62 passenger cars with a minimum trap length of 50m. The average spot speed can be computed from Equation 3 [12].

$$S = \frac{3.6\times\sum_i d/t_i}{n} \qquad (3)$$

Where:
S = the average measured spot speed of vehicle, kph
d = the segment length, m
t = the time required for vehicle (i) to transverse the section, sec
Saturation Flow Rate is the flow achieved if each vehicle consumes 'h' seconds of green time and if the signal were always green, then 's' vehicles per hour could enter the intersection [13]. Due to (COVID - 19) it was not possible to study with high volume. So, we took an approximate number taken from a case study in Qatar [14]. Therefore, the Saturation Headway will be 1.55 seconds. For the signalized intersections, Phase Lengths are collected from Ministry of Works. The value of lost time is taken as the default value (2.5 sec).

5. Calculations

The optimization of the intersections on 16th December Street is done by SYNCHRO program. For the other study locations, we had to optimize manually by following the next steps:

1. Development of a safe and effective phase plan and sequence. By using the same phase plan and sequence for the selected intersections and adding every two closed intersections phase plan with a little modification to eliminate any wasted green time.
2. Determination of vehicular signal needs:

- Timing of "yellow" (change) and "all-red" (clearance) intervals for each signal phase. We assumed the yellow and the all-red intervals combined as 4 seconds.
- Determination of the sum of critical-lane volumes (Vc). By adding the volume in each phase plan and find the maximum one to calculate the phase time using it.
- Determination of an appropriate cycle length (C): we assumed at first two minutes (120 seconds) to check the results and change it later using trial and error.
- Allocation of effective green time to the various phases defined in the phase plan-often referred to as "splitting"' the green Depending on volumes ration in the critical lane-volume.
- Calculating the offset time using equation 2-3 and applying the time on-trial basis in program till we got the best offset.
- Then, we repeat the above procedure for different cycle lengths to find the optimal one.

Now we do not have an equation to find the exact cycle length. So, we will choose different cycle lengths and compare them to get the optimal cycle length. We tried 80,100,120 and 140seconds in VISSIM program and plot the results of the queue length and the capacity for each cycle length in figures 4 and 5.

6. Results and Discussion

Results obtained from the simulation software, VISSIM and SYNCHRO are shown in Tables I-III for different study locations. Optimum cycle length was found to be 100 seconds, in terms of queue length and capacity. It was found through applying different cycles lengths and observing the changes in capacity and queue length. It was plotted with a best fit curve and optimum value was found where maximum capacity and minimum queue length were found. Fig. 4 and 5 present a sample of these curves, which were prepared for Esteqlal highway. Similar curves were obtained for other locations which are not presented here to avoid repetition.
Table I and II show the comparison done with VISSIM software from Esteqlal and Tubli highway, while Table III shows the comparison by SYNCHRO for 16th December highway. The latter was done due to the complex geometry of the intersections at the location which could not be plotted accurately in VISSIM.

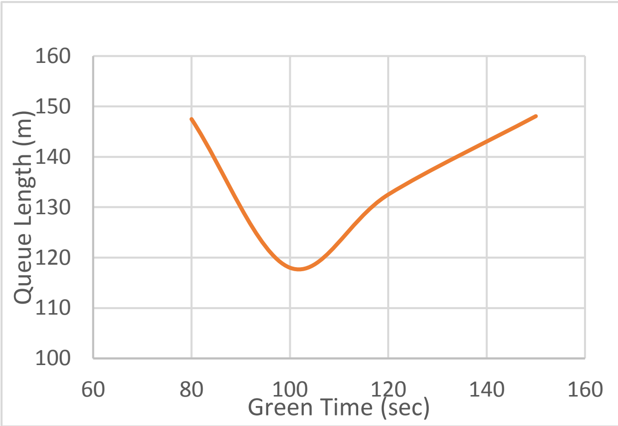

Fig. 4. Determining optimum cycle length using queue length at Esteqlal Highway

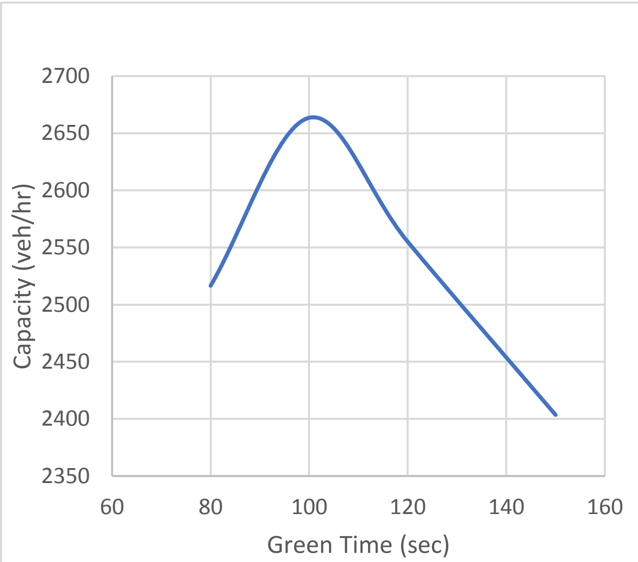

Fig. 5. Determining optimum cycle length using capacity at Esteqlal Highway

TABLE I: COMPARISON BEFORE AND AFTER SIGNAL COORDINATION AT ESTEQLAL HIGHWAY

Comparison aspects	**Before signal coordination**	**After signal coordination**
queue length (m)	1000.38	805.68
Capacity (veh/hr)	3878	5327
Level of Service	E	E
Delay (s)	228.24	144.55

TABLE II: COMPARISON BEFORE AND AFTER SIGNAL COORDINATION AT TUBLI HIGHWAY

Comparison aspects	**Before signal coordination**	**After signal coordination**
queue length (m)	1656.28	1479.15
Capacity (veh/hr)	13461	14787
Level of Service	D	C
Delay (s)	189.53	133.43

TABLE III: COMPARISON BEFORE AND AFTER SIGNAL COORDINATION AT 16TH DECEMBER HIGHWAY

Comparison aspects	**Before signal coordination**	**After signal coordination**
Signal Delay/vehicle (s)	170	162
Stops/vehicle	1.27	1.1
Travel time (hr)	699	679
CO emission (Kg)	50.07	48.44

Significant reductions in delay and queue lengths were observed at all study locations after signal coordination. Especially, at Esteqlal highway, wherein the delay reduced by more than 100 seconds and queue length was reduced by 200m. Similar reduction in queue length was observed at Tubli highway. However, reduction in delay per vehicle was 8 seconds on 16th December highway which would aggregate to a high value for the peak hours. Total travel time for the highway reduced by 20 hours which is an indicative of this fact. Moreover, the capacity for all intersections was increased by more than 1000 veh/hr.

7. Conclusion And Recommendations

The aim of this research was to design coordinated signals at important highways in Bahrain, to create a smooth flow and improving the level of service by minimizing the number of stops and delays. Furthermore, the effects of signal coordination were determined and compared for different scenarios in terms of traffic flow, fuel consumption and CO emissions. On Esteqlal highway, although the level of service did not change, we were able to increase the capacity of the junctions by 1449 veh/hr and reduce the delay by 37%. In Tubli highway the capacity of the junctions increased by 1326 veh/hr, the level of service improved from D to C and the stop delay have decreased by 35%. For 16th December street the queue was reduced by 30% and the average delay per vehicle reduced by 42.5 seconds. All the selected junctions have shown a significant improvement using signal coordination.

This research is very useful for implementation on the selected intersections where it has a lot of advantages in addition to those mentioned above. For example, it reduces the emissions of CO and fuel consumption which will improve the air quality. Our recommendation is to use signal coordination on the selected junctions in the peak hours while keeping the current phase plan for off-peak hours. Other similar locations in Bahrain with closely spaced intersections should be evaluated for possible application of signal coordination.

The present study is the first of its kind for Bahrain and many other GCC countries. Moreover, it provides evidence of the results of application signal coordination in different scenarios. Future work should focus on developing a time period frame to when the coordination starts and end and use both soft wares in each study location to get the most efficient coordination plan and applying the plan on the real intersections to get the actual data and results.

Acknowledgment
Special thanks to the Ministry of Works for helping us during this project, and all traffic engineers whose we communicated with on social media for consulting cases.

References:

[1] Washington state Department of transportation, *Traffic signals,* Juanuary 1, 2020. https://www.wsdot.wa.gov/Operations/Traffic/signals.htm (accessed February 1, 2020).

[2] R. Andalibian and Z. Tian, *Signal timing and coordination strategies under varying traffic demands*, (No. 236-11-803). Nevada. Dept. of Transportation, 2012.

[3] Q. He, K. L. Head, and J. Ding, Multi-modal traffic signal control with priority, signal actuation and coordination, *Transportation Research Part C: Emerging Technologies*, 46, 65-82, 2014.

[4] Transportation Research Board National Research Council, *Highway capacity manual*, TRB Business Office. Washingston DC: national reseach council, 2000.

[5] A. Bull, Traffic congestion: the problem and how to deal with it, In *Traffic Congestion: The Problem and How to Deal with It*, by Alberto Bull, 26. Santigo: Economic Commission for Latin America and the caribbean, 2003.

[6] R. P. Roess, E. S. Prassas, and W. R. McShane, *Traffic engineering*, Pearson/Prentice Hall. United State: Hamilton, 2004.

[7] B. De Coensel, and D. Botteldooren, Traffic signal coordination: a measure to reduce the environmental impact of urban road traffic?, In *40th International Congress and Exposition on Noise Control Engineering (Inter-Noise-2011)* (Vol. 5, pp. 4218-4223). Institute of Noise Control Engineering Japan, 2011.

[8] J. Lv, and Y. Zhang, Effect of signal coordination on traffic emission, *Transportation Research Part D: Transport and Environment*, 17(2), 149-153, 2012.

[9] G. Zhang, X. Jiang, Y. Fan, W. Fan, and T. Meng, Examining the factors influencing the injury severity of crashes on arterials with signal coordination, *Journal of Transportation Safety & Security*, 12(9), 1182-1203, 2020.

[10] R. P. Roess, E. S. Prassas, and W. R. McShane, *Traffic engineering*, Pearson/Prentice Hall. United State: Hamilton, 2004.
[11] Mamatha Srinivas Murthy Sen, *Signalized intersection improvement and analysis using Synchro: For arterial main street and Elm Street Jughandle*, Newark, New Jersey: Department of Civil and Environmental Engineering, 2015.
[12] S. M. Turner, W. L. Eisele, R. J. Benz, and D. J. Holdener, *Travel time data collection handbook*, (No. FHWA-PL-98-035). United States. Federal Highway Administration, 1998.
[13] S. P. Çalışkanelli, F. Coşkun Atasever, & S. Tanyel, Start-up lost time and its effect on signalized intersections in Turkey, *Promet-Traffic & Transportation*, 29(3), 321-329, 2017.
[14] K. Hamad, Estimating base saturation flow rate for selected intersections in Doha, Qatar, *Journal of Traffic and Logistics Engineering*, 168-171, 2015.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The sole author contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The author has no conflicts of interest to declare that are relevant to the content of this article.