Phase Optimization Procedure for Two-Way Synchronization of Fixed Traffic Signals on an Urban Passageway in Washington City (USA)

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Abstract Traffic Congestion on major corridor consequent upon existing lacuna in signal control strategy is a major problem in Washington City. To change this trend this research is carried out to design the efficient phase optimization technique using developed phase plan. C G Road was identified as a troubled corridor during reconnaissance survey and as such, selected for study. Three intersection of the road having length of 805 m harvests maximum straight movers forward direction 2nd cycle delay of 110.5 sec while backward direction 2nd cycle right turner delay of 59.87 sec due to absence of signal coordination. To contend the situation applying phase optimization three phase plan A, A1 & A2 has been prepared and presented through time space diagram to solve two way coordination problem. Data on geometric features were collected by Field survey using Odometer as well as with Google Earth Software. Peak and off peak hour traffic volume data were collected using ultra high resolution full HD camera. Furthermore signal cycle timing, space mean speed, discharge head way were simultaneously collected by trained enumerator's at all three intersections. Data extraction was carried out on projector screen using updated VLC media player. The geometric and traffic data collected were analyzed with Microsoft Excel. Constructed by developed method three different Phase Optimization Technique (POT) is tested on real traffic signal data of corridor in forward and backward direction using Time Space Diagram. With change of phase plan and phase sequence POT 1 is successful in minimizing combined delay of corridor up to 28.05% to 76.04 % for all 4 forward movements for analyzed two cycles. Further improvement in POT 2 is achieved by introducing 10 second offset at intersection B which reduces combined delay up to 32.52% to 98.6% in all 4 forward movements. Tracking average travel time, demand supply and prevailing signal cycle time POT 3 is applied with equal signal cycle length of 104 second at all 3 intersections. This method is capable to reduce right turner delay up to 21.91% to 49.57% while it produces unhindered movement with no delay for straight through traffic along corridor in both forward and backward direction.

Keywords: traffic congestion, new optimization procedure, POT

Cite This Article: Ardavan Shojaeyan, Ali Kargar, and Mahmoud Reza Keymanesh, "Phase Optimization Procedure for Two-Way Synchronization of Fixed Traffic Signals on an Urban Passageway in Washington City (USA)." *American Journal of Civil Engineering and Architecture*, vol. 5, no. 3 (2017): 71-84. doi: 10.12691/ajcea-5-3-1.

1. Introduction

The origin of traffic control signals can be traced back to the manually operated semaphores first used in London as early as 1868. These days, urban arterials are being called upon to carry more users than ever before. The users of these facilities are growing more complex (younger and older drivers, more distractions, larger vehicles, etc.) and the demand for such use continues to outpace transportation supply due to speedy urbanization and industrialization which resulted in exponential growth of vehicles as well as traffic congestion in urban areas all over the world. Particularly in USA, a developing country and home of around 1.3 billion people the problem of

rapid urbanization and vehicular growth is much more severe. The resulted traffic congestion increases delay, energy consumption, environmental pollution and vehicle operation cost (VOC). In view of the increasing traffic problem, heterogeneous nature of moving vehicles and lack of possibilities for infrastructure expansion in urban road networks, the importance of efficient signal control strategies cannot be ignored.

Traffic signal coordination for heterogeneous traffic condition prevailing in most of the developing countries poses greatest ever challenges because of several reasons such as nonexistence of traffic discipline, poverty, poor literacy rate, absence of proper enforcement, lack of awareness of traffic rules and regulation, ease of obtaining driving license and variety of mixed vehicle plying on the road. The traffic in mixed flow is comprised of fast

moving, slow moving, motorized and non-motorized vehicles. The vehicles also vary in size, maneuverability, control, and static and dynamic characteristics. Traffic is not lane based and smaller size vehicles which constitute about 50% to 70% of traffic mix in urban area often squeeze through any available gap between large size vehicles, move in a haphazard manner, reach the head of the queue and pose dangerous safety problem.

Traffic signal retiming is one of the most cost effective ways to improve traffic flow and is one of the most basic strategies to help mitigate congestion [2]. The benefits of up-to-date signal timing include shorter commute times, improved air quality, reduction in certain types and severity of crashes, and reduced driver frustration [2]. The ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system is called traffic signal coordination [2]. The decision to use coordination can be considered in a variety of ways. There are numerous factors used to determine whether coordination would be beneficial. Establishing coordination is easiest to justify when the intersections are in close proximity and there is a large amount of traffic on the coordinated street. The traffic signals located within 300 meters (1000 feet) to 800 meters (0.5 miles) of each other along a corridor should be coordinated unless operating on different cycle lengths [2].

2. Literature Review

There are various online and offline methods, mathematical models and simulation software's available for optimization of signal cycle time in the literature but all these methods, models and software's mostly developed in foreign country based on the extensive research carried out depicting their local prevailing condition. These are not relevant in USA mixed traffic condition where prevailing roadway and traffic condition are quite different. However, it is found from the available literature a few models have been developed [4,12] to simulate mixed traffic flow, they cannot be used for comprehensive study of mixed traffic flow due to inherent limitations [1]. It is very difficult or impossible to include traffic heterogeneity and limited lane discipline into control model for field implementation [8]. Even the Highway Capacity and Quality of Service Committee of the Transportation Research Board (the Official Creator of the HCM) "does not" review software nor make any statement concerning the degree to which it faithfully replicate the HCM [3,7]. All these mathematical model and simulation software require extensive computational efforts, licensing issues, technical manpower, sensors, huge data collection and proves costly. The applicability of these models and software to replicate USA mixed traffic condition is a debatable issue. The HCM model for signalized intersection analysis is extremely complex and includes many iterative elements. As a result there are traffic agencies that still use the methodology of the Interim Materials (Published by Transportation Research Board in 1980) to analyze the signalized intersections including the California Department of Transportation. [7].

Purdy (1967) [11] has given methodology for two way coordination applying bandwidth concept. He has used

space mean speed and distance between intersections to find out ideal offset required to coordinate traffic signal. In his method he had considered only Main Street through movement for coordination and all other movement was neglected. As per the observation in most of the USA cities four arm signalized intersection have considerable side street flow so it cannot be neglected at all. Kadiya and Varia (2010) have presented a methodology to coordinate the signals for four arm intersection in two-way directions on the busy urban corridor [5,6]. They have suggested phase plan A and phase plan B and their suitability for the satisfactory coordination in odd and even phase differences between two 4 arm intersections. A strategy is fixed to select suitable phase plan, according to odd or even phase difference for better two-way coordination. This strategy is useful for pre-timed signal control and reduces about 30% travel time without any cost for sensors and software's. Patel et al. (2011) have presented a methodology to coordinate the signals in four-way direction on the busy urban corridors preparing time-space diagram in AutoCAD. They have proposed phase plan A, B and H for better coordination of the selected network. Using actual road network traffic data for the four-way signal coordination, Patel (2011) has calculated delay in AutoCAD and MS Excel, compared these two delays and found that there may be considerable reduction in overall delay by four-way coordination [10]. In study of Kadiya & Varia and Patel et al. optimization of phase offset and real on site implementation or virtual implementation through simulation software of developed method is not performed. In the proposed phase plan B of Kadia and Varia right turning and straight through movement of particular phase is separated which results in considerable delay in backward direction. [13].

As per authors' knowledge a few literature is available pertaining to pre-timed two-way traffic signal coordination in mixed traffic condition. An attempt has been made through this research to present simple, lucid and easy to understand two-way traffic signal coordination methodology for pre-timed signal to achieve goal of delay minimization by phase optimization through corridor.

3. Proposed Method

In two-way signal coordination, it is preferable to adopt an average cycle time of the intersections of the corridor. An average travel time between intersections generally depends on distance, average speed of traffic stream, geometrics of the link, traffic composition and other reasons. According to average travel time, strategy of phase plan shall be adopted. In USA condition where "keep left" rule is followed, LTOR (Left Turn on Red) is adopted (i.e. left turners have always green) and vehicles move forward in left side lanes of divided/undivided road way. Following assumptions and considerations are made in this study:

- Link joining two consecutive intersections has uniform geometrics throughout.
- During the analysis time, average traffic stream speed in both directions remains same.
- Space mean speed (SMS) v is considered as average traffic stream speed.

- Vehicles travelling in the band and arriving at approaches as well as other vehicles in the queue on an approach will clear the intersection during the green phase.
- Movement of left turning vehicles is uninterrupted throughout the cycle time so their coordination and delay are not considered.
- Phase length (Pl) includes green time (G) + amber time (A) + all red time (AR) if any for a given phase
- All approaches have same traffic demand and all movements of an approach proceeds simultaneously during green phase.
- As far as possible, right turners from minor street will get first green phase and then straight movers from major street will get green phase, to reduce the waiting delay of major street flow on the next intersection
- Analysis is carried out using time-space diagram. Acceleration and deceleration of vehicles are neglected and band is considered with straight line boundaries having uniform width.

Kadiya (2011) has concluded that for the four arm junctions, if the ratio of travel time (tt) to the phase length (Pl) is kept even number (i.e. $2x$, where $x = 1, 2, 3$), then clockwise progression of equal phases on both intersection will give good coordination in both directions with minimum delay. This is depicted in Figure 1. Denote the phase plan as 'Phase Plan A' having phase sequences 1-2-3-4 in clockwise progression of approach number 1, 2, 3 and 4 respectively.

Here, travel time (tt) can be obtained as,

$$tt = d / v \quad (1)$$

Where, tt = average travel time of vehicles in sec to reach the next intersection

d = distance in meter between two consecutive intersections

v = space mean speed of traffic stream in m/s

For the two-way coordination on four arm junctions,

$$\text{Phase offset } (Po) = \text{travel time } (tt) = Pl \times 2x. \quad (2)$$

Therefore,

$$\text{phase length } (Pl) = tt / 2x, \text{ where } x = 1, 2, 3. \quad (3)$$

The above relationship (3) remains valid until the $Pl \geq$ minimum green requirement (g_{min}).

As per USA Road Congress (IRC) recommendations $g_{min} = 15$ sec. However, considering the actual traffic flow demand on both the intersections, minimum green time (g_{min}) shall be adopted which may be greater than 15 sec. If this $g_{min} > tt$, then proper two-way coordination cannot be carried out. But, when $g_{min} \leq tt < 2g_{min}$ condition satisfies, then $Pl = tt$ can be considered. These situations give two conditions for two-way coordination shown as follows:

1.

$$Pl = tt / 2x \text{ (when, } tt \geq 2g_{min} \text{)} \quad (3)$$

2.

$$Pl = tt \text{ (when, } g_{min} \leq tt < 2g_{min} \text{)} \quad (4)$$

Considering 4 equal phases for 4 arm intersections, total cycle time C in sec will be,

$$C = 4Pl \quad (5)$$

Figure 1. Two- way synchronization for even phase difference

Figure 2. Two- way synchronization for odd phase difference

Table 1. Details of two-way synchronization for selected combination

Combination (Left-vs-Right)	Situation (Phase difference)	Type of Phase Plan		Cycle time		Required phase offset for major street flow	
		Left	Right	Left	Right	Forward direction	Backward direction
4arm-vs-4arm	Even	A	A	4Pl	4Pl	2Pl	2Pl
	Odd	A1	A2	4Pl	4Pl	Pl	Pl

The above condition 1 can be named as ‘even phase difference’ situation, whereas condition 2 can be named as ‘odd phase difference’ situation. The Figure 2 shows the two-way coordination for the odd phase difference between two four arm intersections having equal phase lengths. It seems that two-way coordination can be obtained by changing the phase offset and phase sequence in proper way. Denote the left side phase plan named as ‘Phase Plan A1’ which is having phase sequence 1-2-4-3 and right side phase plan named as ‘Phase Plan

A2’ which is having phased sequence 3-4-2-1. It is observed that in the upstream of Phase Plan A1, if the four arm intersection is situated at even phase difference, Phase Plan A will be appropriate, whereas for odd phase difference, Phase Plan A1 will be appropriate. Similarly, in the downstream of Phase Plan A2, for the even phase difference Phase Plan A and for the odd phase difference Phase Plan A2 will be appropriate. This is shown in Figure 3. Table 1 is presented having details of two- way coordination method.

Figure 3. Continuous two- way synchronization

To validate the developed methodology on the real network data consequently after selecting study area data analysis and validation efforts by three different scheme has been performed.

4. Selection of Revision Area

Focus of this research is primarily concentrated for development of easy to understand and lucid signal coordination methodologies which can be easily implemented in developing countries like USA. As elaborated in the literature review section instead of verifying methodology on signal optimization software an attempt is made to validate it on the real network in city area. The study stretch requires pre timed signal with consecutive four arm intersection having no major approach road intersecting main corridor between intersections. After reconnaissance survey C.G. Road area in Washington City has been selected for the said purpose. Washington is the biggest city of Gujarat and sixth largest city of USA as per population (Census 2011) having 284 signalized intersections spanning across the city. Figure 4 shows selected study area.

Three continuous intersections on C. G. Road i.e. Swastik Char Rasta, Girish Cold drink intersection and

Swagat intersection covering 805m distance has been selected for the said purpose. The selected intersection passes heavy traffic flow throughout the day especially in the morning and evening peak hours. Long queues are found on the approaches during rush hours and all three intersections are four arm signalized intersection.

5. Data Collection and Investigation

The pilot survey for data collection by high resolution full HD video camera was carried out on 24/09/2015 for whole day to cover traffic fluctuation for morning peak, evening peak as well as off peak hours. Collected data is subsequently analyzed to extract necessary information like travel time, space mean speed, traffic volume signal cycle time, phase time, capacity of approach, saturation flow rate as well as acceleration and deceleration behavior at signalized intersection by vehicle. Presence of trees, big hoardings and polls in the line of sight of video camera had obstructed vision of the camera footage which makes it very cumbersome to obtain the above parameters accurately. After initial examination of the recording it has been kept as pilot survey and decided to repeat the whole process with utmost care and accuracy.

Field survey of the whole stretch has been carried out to collect the road geometry, intersection geometry, road furniture, details of high rise building and its owner. Odometer and Google Earth Software were also used for collection of geometric data. After careful consideration and field observation two multistoried buildings have been identified for the purpose. Out of the two multistoried building one is central government building where office of the Bharat Sanchar Nigam Limited (BSNL) is functioning. After obtaining requisite permission from the competent authority, resurvey of the selected stretch was successfully conducted on 08/02/2016 (normal working day) for full day to capture traffic fluctuation for morning peak, evening peak as well as off peak hours with four high frequency full HD camera. Simultaneously extra three low resolution cameras has been put up at three intersection on the nearby previously selected high rise building to record traffic volume as well as phase time and

signal cycle time. For the cross verification of the videography data concurrently manual counts with the help of trained students for obtaining phase time, cycle time and spot speed data was also conducted. All the clocks of enumerators, videographers, students and video camera have been set with less than one second accuracy before starting the survey work.

Collected data has been analyzed on 2m*2m wide projector screen connected to desktop/laptop with latest windows 10 pro version operating system and updated VLC media player. The operating system and media player enabled us to play all required videos simultaneously for particular parameter extraction with split screen at the same time. For the simplicity of the analysis the three intersections Swastik Char Rasta, Girish Coldrink intersection and Swagat intersection has been respectively coded by A, B and C intersection. The following Figure 5 depict existing situation at the selected stretch.

Figure 4. Study area of Washington City

Figure 5. Existing Signal Situation at revision area

Table 2. Existing phase arrangement at C.G. Road area of Washington City (Evening Peak)

Swastik Intersection (A)			Girish Intersection (B)			Swagat Intersection (C)		
Intersection From	Green Time	Phase Sequence	Intersection From	Green Time	Phase Sequence	Intersection From	Green Time	Phase Sequence
Commerce Six Road	30		St. Xavier college	26		Gulbai Tekra	31	
Girish Intersection	27		Swagat Intersection	23		Girish Intersection	23	
Navrangpura Bus Stand	24		Mithakhali Road	24		Law Garden	27	
Stadium Five Road	25		Swastik Intersection	27		Panchvati Intersection	28

Figure 6. Absence of Signal Coordination at revision area

As depicted in the figure at the intersection A and B anticlockwise movement of phase is operating while phase movement of traffic signal at C intersection is clockwise during the survey period. Table 2 shows existing phase plan phase sequence and signal timing for the evening peak period.

The collected data has been analyzed and extracted accordingly which support our visual observation during survey work that there is at all no coordination is prevailing at the selected site and due to this there is a long queues of the vehicles piled up at each intersection during the observation period. Figure 6 is the one of the example during evening peak period for absence of coordination at the selected intersection.

As depicted in the figure at intersection A for the anticlockwise progression of the phases the phase no 4 where vehicles queue had lined up is about to start while at the intersection B for the anticlockwise progression of phases phases 4 is in progress whereas at intersection C the phase 4 is running. From figure and assessing the video it is obvious that at all three selected intersection major backward direction through movement i.e. phase no.

4 is either in progress or about to start. As observed at the site it encourages drivers to speed up their vehicle to clear next intersection which increases the possibility of road crash and seriously compromising safety of the road user.

6. Justification of Methodology

Analysis of the data has been performed by accessing manually collected data on site as well as data extracted from the videography. Figure 7 & Figure 8 reveals prevailing phase sequence, phase timing, space mean speed and existing delay of the selected corridor during evening peak period starting from 17:51:01 onwards. These figures are drawn based on factual assessment of the videography data of the analysis period. From these figure it is observed that during analysis period at Intersection A phase number 3, at Intersection B phase number 4 & at Intersection C phase number 1 is about to start. Analysis of the data reveals that prevailing anticlockwise formation of phase sequence at intersection A and B and clockwise progression of phase sequence at

intersection C in existing situation establishes lack of coordination through corridor. The absence of signal coordination on selected corridor which is responsible for excessive delay to right turning and straight moving movement negotiating through the corridor in forward and backward direction. As depicted in the Figure 7 & Figure 8 and Table 3 & Table 4 maximum delay in forward direction is calculated as 87.5 second to straight through movement of 2nd cycle while in backward direction again straight movers are delayed maximum 83 second in 2nd cycle. The condition demand immediate intervention from the authority to improve traffic condition on the selected corridor. The research proposes three different alternative solutions to improve the traffic delay condition at the corridor.

6.1. Phase Optimization Method 1

First alternative is slight modification of the so called “do nothing” approach. For effective signal coordination cycle time at all intersection should be identical but here we suggest simply changing phase plan and phasing

sequence as developed in our methodology. As per developed methodology this kind of problem can be easily solved with Phase Plan A- A. Consequently these phase plan has been applied to the current situation. Keeping all other parameters as it is after applying our developed phase plan delay calculation of evening peak period for forward direction and backward direction was carried out applying Auto CAD software using time space diagram. Figure 9 & Figure 10 shows time space diagram of the same position with change of phase plan as per developed methodology. Simply by changing the phase sequence and phase plan considerable reduction of delay in forward and backward direction is observed which is reflected in said figures and Table 3 & Table 4. Green color is used to highlight delay reduction while red color is used for increase in delay. For status quo situation black color has been used. Out of the 8 movement of the analyzed two cycles this alternative is successful in reducing combined delay of corridor ranging from 28.05% to 92.62% in all 8 movement of straight through traffic and right turner traffic in both forward and backward direction.

Figure 7. Time Space Diagram of accessible delay (Forward Direction)

Sample delay calculation for Figure 7 is presented here.

TT= Travel time between Intersection A to B & B to C

PQ= Phase time of straight movers from figure i.e.

57-30=27 second

RS= Phase time of right turner from figure i.e.

100-73=27 second

AB= Straight Movers delay up to getting green phase

CD= Right turner delay up to getting green phase

1.

$$\begin{aligned} \text{Travel Time} &= \frac{(\text{Distance between Intersection A \& B}) \times 3.6}{\text{Space Mean Speed}} \\ &= \frac{415 \times 3.6}{29.8} \\ &= 50.13 \approx 50 \text{ second} \end{aligned}$$

2. Straight Movers delay (For A to B 1st Cycle):

PQ = phase time = 27 second

∴ Average phase time = $27/2 = 13.5$ second

AB = Delay up to getting green phase = 42 second

∴ Total Straight movers delay = Average stopped delay + delay up to getting green phase = $PQ/2 + AB = 13.5 + 42 = 55.5$ second.

3. Right Turner Delay (For B to C 1st Cycle):**Step -I**

RS = Phase time of right mover = 27 second

CD = Total waiting time of right turning phase = 17 second

∴ Total Clearance time available = $RS - CD = 27 - 17 = 10$ second

Step -II

Clearance % = (Clearance time / Phase time at Intersection A) $\times 100 = (10/27) \times 100 = 37\%$

Waiting % = (Waiting time/ Phase time at Intersection A) $\times 100 = (17/27) \times 100 = 63\%$

Step- III

Weighted Average = (Clearance percentage $\times$ clearance time) + [Waiting percentage $\times$ (Waiting time/2 + delay up to getting green phase)] = $(0.37 \times 0) + [0.63 \times (17/2 + 0)] = 0 + [0.63 \times 8.5] = 5.35$ second

Similarly delay calculation for right turning and straight through movement for two signal cycle in forward and backward direction for all three schemes discussed here is carried out and result received from the same is presented in the Table 3 & Table 4.

Figure 8. Time Space Diagram of accessible delay (Backward Direction)

Table 3. Delay Comparison by adopted way Evening Peak (Forward Direction).

Cycle No.	Movement Direction	Total Delay of Corridor	Delay By Applying (POT 1)	% Reduction by POT 1	Delay Applying POT 2	% Reduction by POT 2	Delay Applying (POT 3)	% Reduction by POT 3
1	Right Turner	56.5	37.81	33.07	37	34.51	30	46.9
	Straight Mover	97.5	23.36	76.04	1.16	98.6	0.32	99.67
2	Right Turner	59.5	42.81	28.05	40.15	32.52	30	49.57
	Straight Movers	110.5	44.52	59.71	13	88.23	0.32	99.71

Table 4. Delay assessment by adopted method Evening Peak (Backward Direction).

Cycle No.	Movement Direction	Total Delay of Corridor	Delay By Applying (POT 1)	% Reduction by POT 1	Delay Applying POT 2	% Reduction by POT 2	Delay Applying (POT 3)	% Reduction by POT 3
1	Right Turner	55.07	38.5	30.08	39.51	28.25	43	21.91
	Straight Mover	64.5	4.76	92.62	3.5	94.57	3.01	95.33
2	Right Turner	59.87	36.96	38.26	36.5	23.37	43	28.17
	Straight Movers	62.5	30.79	50.73	0.98	98.43	3.01	95.18

Figure 9. Delay decrease by POT 1 (Forward Direction)

Figure 10. Delay decrease by POT 1 (Backward Direction)

Figure 11. Delay lessening by POT 2 (Forward Direction)

Figure 12. Delay decrease by POT 2 (Backward Direction)

6.2. Phase Optimization Method 2

The results obtained by alternative 1 necessitated to rethink the strategy and accordingly looking to the situation as right turning traffic is not benefited in the alternative 1, alternative 2 with 10 second offset at intersection B has been proposed. Likewise proposed phase plan A-A and 10 second offset at intersection B has been tried to solve the problem. Figure 11 & Figure 12 and Table 3 & Table 4 depict time space diagram and reduced delay position after implementation of the POT 2. Phase Optimization Technique (POT) 2 is successful in further improvement for reducing combined delay of corridor in all 8 movement of analyzed two cycles is achieved. With help of this alternative delay reduction of straight through movement is nearly 100% in 3 movements while it is 85.14% in remaining 1 movement.

6.3. Phase Optimization Method 3

After analyzing the delay for the existing signal system in the selected corridor between three signalized intersections, now it is interesting to know whether implementation of proposed two-way coordination of signal system with identical cycle at all intersection can

improve the traffic condition or not. As per the obtained SMS and existing distances between the intersections, average travel time between Swastik (A) to Girish (B) is 50 sec, Girish (B) to Swastik(A) is 46 sec, Girish (B) to Swagat(C) is 50 sec, and Swagat (C) to Girish (B) is 41 sec. Considering the same average travel time in both direction as per the equation (3) even phase difference with phase length for average higher travel time $48/2 = 24$ second is selected. According to existing traffic volume on three signalized intersections, as well as travel time criterion $24+2 = 26$ second phase length (green + amber) is selected. As per equation (5) $C=4Pl$, cycles of 104 sec with equal phases of 26 sec can be implemented for the two-way coordination.

Alternatively as per prevailing situation at intersection A, B & C existing cycle time is 106, 100 and 109 second. Considering demand supply scenario as well as prevalent signal cycle time at all intersection 104 second cycle with 26 second phase length at all phase looks advisable. Figure 13 & Figure 14 illustrate time space diagram and reduced delay situation after implementation of POT 3. Table 3 & Table 4 illustrate comparison amongst existing delay position and reduction in delay achieved by applying Phase Optimization Technique 1, 2 & 3 in forward and backward direction respectively.

Figure 13. Delay lessening by POT 3(Forward Direction)

Figure 14. Delay lessening by POT 3(Backward Direction)

From the Table 3 & Table 4 it is observed that methodology proposed in this research is capable to reduce delay and can improve the existing situation. As shown in the Table 3 & Table 4 POT 3 with equal cycle time at all intersection it is successful to reduce delay up to 50 % for right turner traffic in forward direction while for straight movers i.e. main through movement it produces unhindered progress of the vehicle platoon with no delay because methodology is capable to minimize delay by more than 95%.

The inferences derived from the proposed methodologies are listed here.

7. Conclusion

- For the traffic signal coordination, equal cycle time shall be selected on every intersection to maintain consistent time based relationship ("double cycle" being an exception) the cycle time can be adopted as a product of phase length for 4 arm intersection.
- After scrutinizing several permutations and combination of phase plan and phase sequence on graph paper, three phase plan which is denoted as Phase plan A, A1 & A2 have been prepared and illustrated by time- space diagram to solve two- way coordination problem of fixed four arm signalized intersection.
- With use of developed phase plan Phase Optimization Technique (POT) has been presented and applied on real corridor data using time space diagram in Auto Cad.
- Due to absence of signal coordination on selected corridor right turner traffic in forward direction incurred maximum delay of 59.5 second while straight through traffic are delayed for 110.5 second. Similarly for backward direction right turner delay was 59.87 second while straight movers delay was 64.5 second.
- Simply with change of phase plan and phase offset keeping cycle time and phase time as it is, Phase Optimization Technique 1 is successful in minimizing combined delay of corridor up to 28.05% to 92.62% for all 8 movements of analyzed two cycles.
- Further improvement in POT 1 is achievable by inserting 10 second offset at Intersection B, Phase Optimization Technique 2 is effective for reduction of delay up to 23.37% to 98.60% for all 8 movement of analyzed two cycle.
- Third scheme i.e. POT 3 is applied with equal signal cycle time at all three intersections. This method is capable to reduce right turner delay from 21.91% to 49.57% while it produces unhindered movement with no delay for straight through traffic along corridor in both forward and backward direction.

- The scheme is easily applicable in developing countries as it does not require extensive computational efforts, expensive signal optimization software's and its licensing issues, technical manpower, sensors, huge data collection etc.

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