Critical Review and Analysis of Traditional Approach for Pre-Timed Traffic Signal Coordination and Proposed Novel Approach

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Abstract

Signal coordination is perceived by many agencies as a beneficial improvement to the community or corridor under consideration. In this paper, a critical review and analysis of the previously developed methodology for the pre-timed two- way signal coordination and coordination at network level has been presented. Coordination has been achieved by adopting different phase plans to reduce the vehicular delay. The study found that both the methodologies can reduce vehicular delay ranging from 30% to 60% for the assumed ideal conditions. Methodology of signal coordination should be upgraded based on Time- of-Day (TOD) intervals to suit for actual traffic conditions of road network such as, change in traffic flow, change in average journey time, change in geometrics, etc. The result obtained by both methodologies has been critically reviewed and novel approach of signal setting using disutility index (DI), simulation software's, soft computing techniques and mathematical modeling is proposed.

Key words: Signal Coordination, Disutility index (DI) Time- of -Day (TOD) intervals, Soft Computing, Simulation.

1. Introduction

Traffic congestion in urban areas has become a global phenomenon now a day. Speedy urbanizatation and industrialization have caused radically growth of vehicles all over the world. Particularly in India, a developing country the problem of rapid urbanization and increase in growth of vehicle is much more severe than other part of the world considering the speedy increase in population of the country. In view of the increasing traffic congestion and lack of possibilities for infrastructure expansion in urban road networks, the importance of efficient signal control strategies, particularly under saturated traffic conditions, can hardly be overemphasized. The difficulty like congestion, delay, energy consumption, environmental pollution, etc which ultimately leads to increase in vehicle operation cost (VOC) still remain in question if the traffic signals are not coordinated. Coordination of signals is achieved when the flow of traffic on a given phase of movement at one intersection will receive green phase on its arrival at the next signalized intersection. It enhances progressive movement of traffic streams at some specific speed without enforced halts and reduced overall delay. It reduces the speed variations and provides smooth traffic operation, which increases capacity, decreases energy consumption and reduces air and noise pollution, thus reducing overall Vehicle Operation Cost. Goal of signal coordination is to get the maximum number of vehicles through the system with the smallest amount of stops in a comfortable manner.

In urban areas, traffic volumes are higher during peak hours in all the approaches of the signalized intersections, i.e. on the major and minor streets. Therefore, it is necessary to coordinate the signals of the network in all the directions, rather than to coordinate on a single corridor. It is quite difficult to improve the performance of urban traffic signal control system efficiently by using traditional methods of modeling and control because of time-variability, non-linearity, fuzziness and non determinacy in the system. It becomes the research hotspot in this area to apply artificial intelligence methods to urban traffic signal control system.

In fact, urban traffic signal control is the product of vehicle modernization: in order to separate the traffic flows that may result in traffic conflict, it is necessary to guide and schedule it effectively by using traffic signals. The problem of urban traffic is more and more serious, and many people are trying hard to solve it. On one hand, people are ceaselessly presenting new theories and new methods, and on the other hand, many area coordinated traffic control systems based on computers are developed one after the other. Generally, traffic control methods include fixed-time control, time-of-day control, vehicle actuated control, semi-actuated control, green wave control, area static control and area dynamic control.

In order to solve some of the previously mentioned problems it is necessary to design an optimum signal timing plan. The signal timing plans seek to optimize (i) the cycle length of a signal, that is defined as the duration time from the center of the red phase to the center of the next red phase (ii) green splits, the percentage of time devoted to each phase during a cycle and (iii) offsets, the phase difference between signal transitions at consecutive intersections regulated by traffic signals.

2. Literature review

Taxonomy of strategies that can be applied to the traffic signal control can be seen according to the representation of the real traffic network: non-adaptive traffic signal control approaches and adaptive traffic signal control approaches. The non-adaptive signal control approaches represent the transportation system by means of macroscopic models or microscopic traffic simulators. These methods allow different action within the traffic system to be assessed but they do not use data on existing traffic conditions when the traffic signal systems are activated. They can be classified according to two temporal planning contexts: static methods and dynamic methods.

The static methods assume a stationary situation of the traffic and their objective is to obtain the signal regulation of a set of intersections within the network. This problem has been formulated through a Mathematical Program with Equilibrium Constraints (MPEC). The results of these models are signal regulations with fixed times for each cycle. A fairly large volume of research has been focused on these methods for optimizing timing plans. Most of the works use techniques such as genetic algorithms, queuing theory, dynamic programming, neural networks, etc. A detailed discussion of these methods is beyond the scope of this paper but the following works of the application of these techniques. Van Leeuwaarden (2006), Rouphailark et al. (2000), López et al. (1999), Spall and Chin (1994), Sánchez et al (2008), Dong et al. (2005), Sánchez et al. (2004) can be seen as a representative sample.

The dynamic methods consider the non-stationary demand patterns. These methods divide one day into intervals, known as Time-Of-Day (TOD) intervals, and it is assumed that for each TOD interval the traffic flow is roughly stationary. Relatively little attention has been devoted to these methods. Papers to address this matter, Wong & Woon (2006, 2008) present a novel method for optimizing traffic timing plans via the use of clustering algorithms and optimization methods to generate TOD intervals automatically. A paper by Li et al. (2005) discusses that it is an important aspect in urban traffic control to make the arterial traffic operate under good condition. The prevalent method is by coordinating the traffic signal lamps to obtain the progression on a corridor. They used minimizing Performance Index (PI), maximizing the bandwidth of progression, practical methods and theoretical methods. This paper is for pre-timed arterial traffic control. It can enhance the practical methods, and make traffic signal transition speedy and smooth to a certain extent. Andreas et al. (2008) have carried out survey to cover the research in the area of adaptive traffic control with emphasis on the applied optimization methods. Method uses Bi-level formulation, and dynamic for the online. There are several models for trace networks, which are not based on the periodic behavior of online systems to perform coordination. Instead they assign green time to phases in some order, which is optimal given the detected and predicted trace. Yin and Chen (2009) have considered the optimal traffic signal setting for an urban arterial road by introducing the concepts of synchronization rate and non-synchronization degree. Method uses a mathematical model. They have developed algorithm to solve this optimal traffic control signal-setting problem to each lane.

Chhanya (2004) has developed a function to convert queue length into green time for the mixed traffic condition from the observed clearance times of different types of vehicles in the queue with different positions. Using this function and detected queue length a procedure for adaptive traffic control signal (ATCS) is developed, which in turn adjusts the traffic signal control adaptively. Kadiya and Varia (2010) have presented a methodology to coordinate the signals in two-way directions on the busy urban corridor. They have suggested two-phase plans and their suitability for the satisfactory coordination in odd and even phase differences between two signals. 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 corridor in AutoCAD. Using actual road network traffic data for the four-way signal coordination, Patel (2011) has calculated delay in AutoCAD and found that there may be considerable reduction in overall delay by four-way coordination.

Other techniques such as genetic algorithms (Park et al., 2003) have been used in order to deal with this problem. Varia et al. (2013) used the genetic algorithms technique for joint optimization of signal setting parameters and dynamic user equilibrium (DUE) traffic assignment for the congested urban road network. The methodology developed in such a way that joint optimization of signal setting parameters with DUE is obtained. The proposed method is applied to the real network data of Fort Area of Mumbai city (India) comprising of 17 nodes and 56 unidirectional links with 72 Origin–Destination pairs, where all the 17 nodes are signalized intersections. The traffic flow condition for the optimized signal setting parameters is considerably improved compared to the existing signal settings.

3. Adopted methodology for two way coordination.

Kadiya (2011) has suggested methodology for two way coordination. On the congested corridor, when the traffic flow on both the directions (forward and backward) is heavy, two-way coordination is desirable to provide minimum delay to the vehicles. If the intersections are close (less than 1000 m), it is advisable to adopt equal signal cycle time and equal phase time on each intersection to avoid unnecessary delay to the vehicles and also to provide smooth uninterrupted flow pattern in both the directions.

Proper phase plan and its sequence are also very important to avoid delay. In this study four arm junctions with four phases are considered, which are generally found in Indian cities. It is also considered that left turners have always green. Travel time in both directions is also assumed same. The phase sequence shall be adjusted such that right turners entering to main corridor and straight movers entering to main corridor on same direction should have minimum time difference to reach at the next intersection. If straight movers are more (i.e. through traffic flow is higher) than right turners, straight flow should be given second priority to get minimum delay on next intersection for clearance. Thus, through traffic and right turners should get quicker clearance on major corridor in both the directions.

Unequal phase timing and improper phase sequence on two consecutive four arm junctions give larger delay to the vehicles, which is shown in Figure 1. It can be seen that vehicles from the Intersection-I have to wait in queue for lager time interval on the Intersection-II in the forward direction. Similarly vehicles from Intersection-II have to wait for longer time interval on the Intersection-I in backward direction. If the equal phase timings and proper phase sequence are provided, then vehicles have to wait considerably lesser time interval in a queue, which is shown in Figure 2.

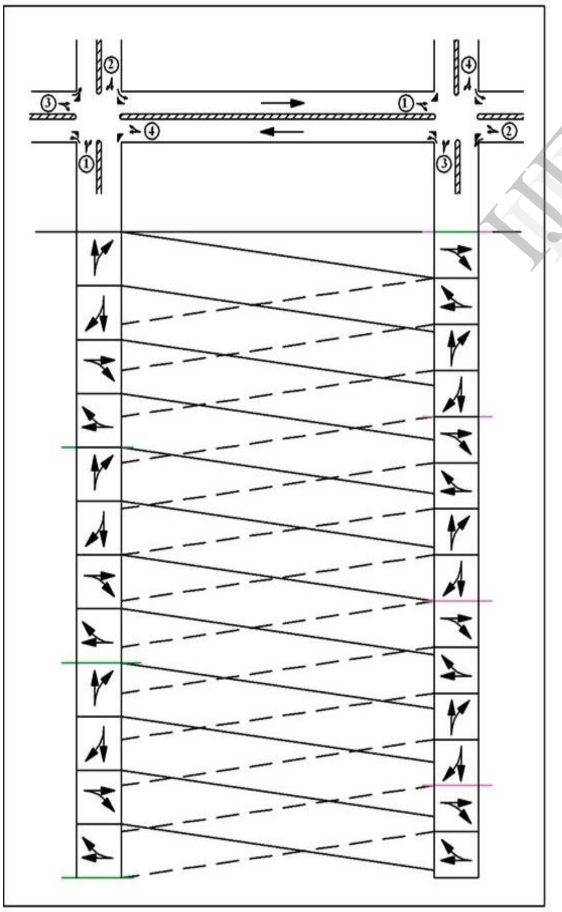


Figure 1: Unequal phase timing, improper phase sequence

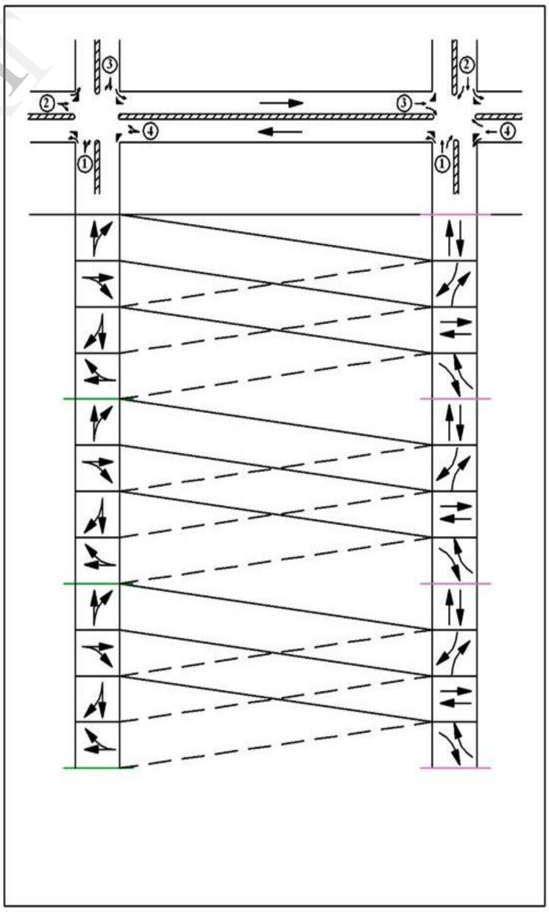


Figure 2: Equal phase timing, proper phase sequence

For the unequal phase timing and improper phase sequence in Figure 1, Delay for right movers in forward direction is minimum three phase and for straight movers it is of one phase. Backward direction delay for straight & right movers is one phase. Whereas for the equal phase timing and proper phase sequence in Figure 2, Delay for right movers in forward direction is one phase and for straight movers no such delay. Similarly, delay for right movers in backward direction is one phase and for straight movers no such delay.

In two-way signal coordination, it is preferable to adopt an average cycle time of the intersections of the corridor. For example, if cycle time on the intersections is varying between 100 sec to 140 sec, than an average cycle time of 120 sec can be adopted on each intersection. Now, if the traffic flow on all the approaches is almost same during the peak hours, the equal phase timing of 30 sec (green + amber time) for each phase on four phase cycle of 120 sec can be adopted. A Phase difference (i.e. integer of average travel time of traffic stream between two consecutive intersections / adopted phase time) between intersections generally depends on distance, average speed of traffic stream, geometrics of the link, vehicle composition and other reasons. According to phase difference, strategy of phase plan shall be adopted. For the simplicity of traffic flow operation, two types of phase plans, Phase plan-A and Phase plan-B are considered for the four arm junctions that are shown in Figure 3.

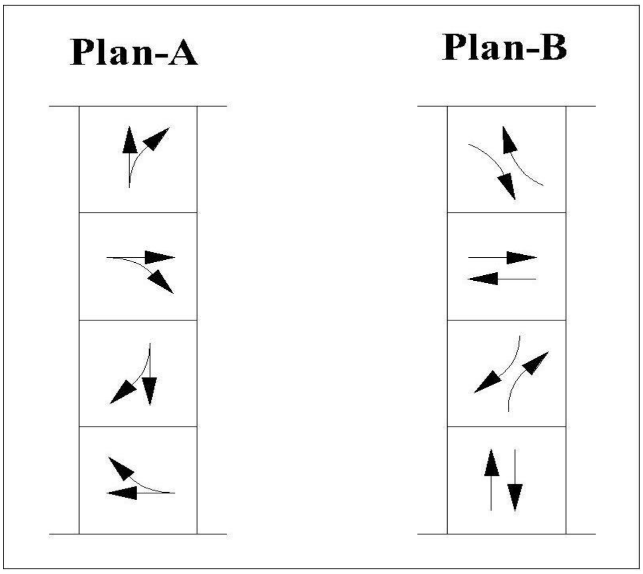


Figure 3: Phase Plan-A and Plan-B

The above plans are tested for the different phase difference, like 1 phase, 2 phase, 3 phase, 4 phase and so on phase differences. The following figures 4 and 5 are showing the adequacy of phase plan A and B for the odd and even phase differences respectively. For the phase timing of 30 sec, (i) 1 phase difference can be taken for 0 to 40 sec average travel time, (ii) 2 phase difference can be taken for 41 to 70 sec average travel time, (iii) 3 phase difference can be taken for 71 to 100 sec, (iv) 4 phase difference can be taken for 101 to 130 sec, and so on. The table 1 and 2 are showing the delay calculations for odd and even phase differences respectively.

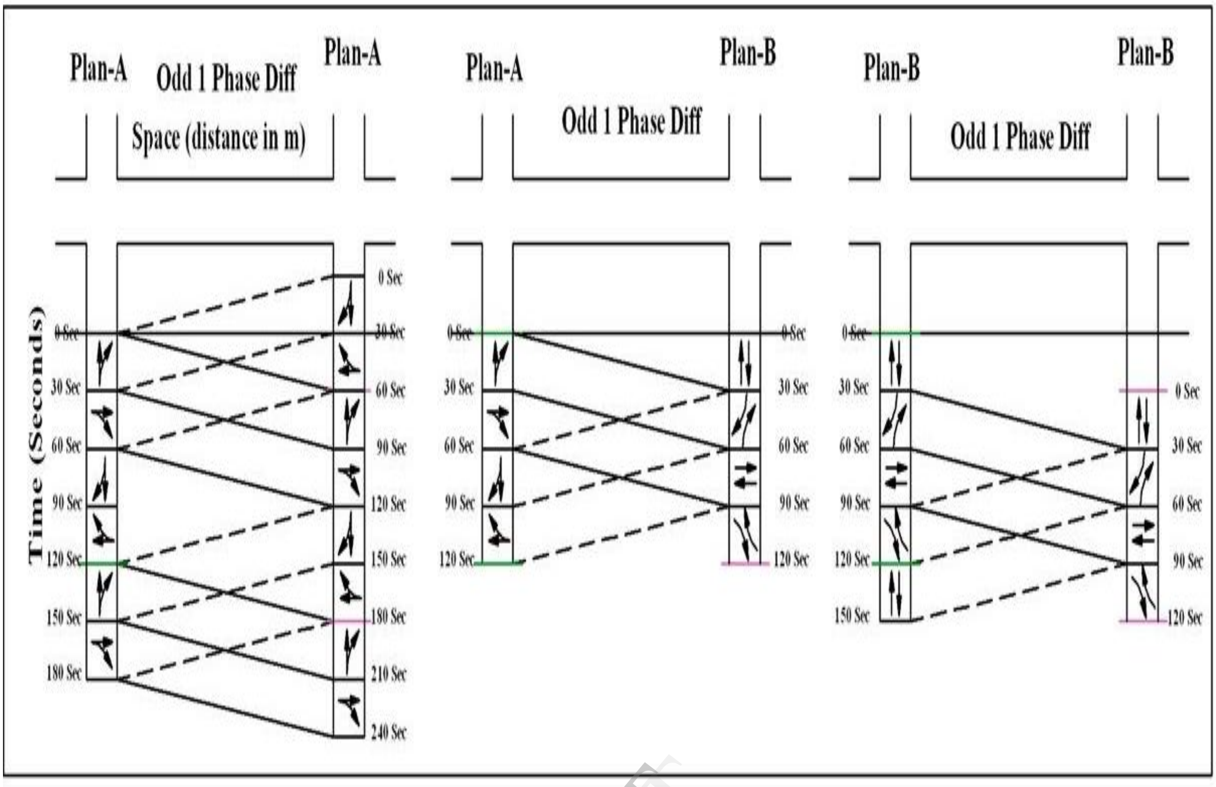


Figure 4: Strategy for odd phase difference

Table 1: Delay calculation for odd phase difference

		Plan A To A		Plan A To B		Plan B To B	
No	**Direction**	**Average Forward Direction Delay(Sec)**	**Average Backward Direction Delay(Sec)**	**Average Forward Direction Delay(Sec)**	**Average Backward Direction Delay(Sec)**	**Average Forward Direction Delay(Sec)**	**Average Backward Direction Delay(Sec)**
1	R to R	15	75	45	15	45	0
2	R to S	15	75	15	15	15	75
3	S to R	0	45	15	0	15	75
4	S to S	0	45	0	0	0	45
	Total	**30**	**240**	**75**	**30**	**75**	**195**
	Combined	**270 Sec**		**105 Sec**		**270 Sec**	

(Where R=Right turners and S=Straight movers)

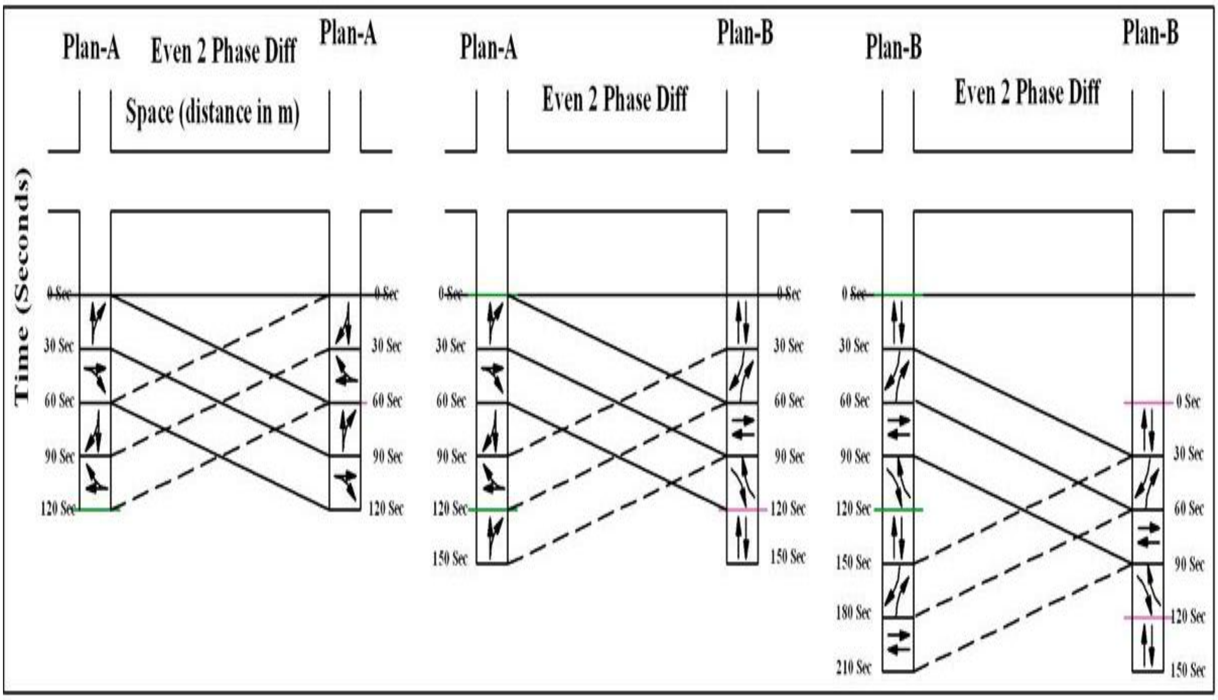


Figure 5: Strategy for even phase difference

Table 2: Delay calculation for even phase difference

		Plan A To A		Plan A To B		Plan B To B	
No	**Direction**	**Average Forward Direction Delay(Sec)**	**Average Backward Direction Delay(Sec)**	**Average Forward Direction Delay(Sec)**	**Average Backward Direction Delay(Sec)**	**Average Forward Direction Delay(Sec)**	**Average Backward Direction Delay(Sec)**
1	R to R	15	15	15	0	45	45
2	R to S	15	15	0	0	15	15
3	S to R	0	0	0	75	15	15
4	S to S	0	0	75	75	0	0
	Total	**30**	**30**	**90**	**150**	**75**	**75**
	Combined	**60 Sec**		**240 Sec**		**150 Sec**	

(Where R=Right turners and S=Straight movers)

Looking at the above strategies for odd and even phase differences it can be concluded that

- For the odd phase difference, phase plan A to B gives minimum overall average stopped delay in both directions (105 sec) compared to phase plan A to A and B to B (270 sec). Hence, phase plan A to B is preferable for the odd phase difference.
- For the even phase difference, phase plan A to A gives minimum overall average stopped delay in both directions (60 sec) compared

to phase plan A to B (240 sec) and B to B (150 sec). Hence, phase plan A to A is preferable for the even phase difference. In the corridor if previous intersection has plan B and even phase difference, then plan B to B can be preferred.

- Phase plan A gives early removal of straight and right turners in one phase compared to phase plan B. However, where right turners are significant on all the approaches then phase plan B can be adopted.

The author (Kadiya, 2011) has suggested suitable plan combinations for the various situations of the phase differences (Table 3). It is concluded that for the odd phase differences A vs. B or B vs. A plans are suitable, and for the even phase differences A vs. A or B vs. B plans are suitable

Table 3: Phase plan for different phase

Sr. No	Phase Difference	Adoptable phase plan
1	One	A ⟷ B or B ⟷ A
2	Two	A ⟷ A or B ⟷ B
3	Three	A ⟷ B or B ⟷ A
4	Four	A ⟷ A or B ⟷ B

4. Application of two way coordination methodology

Kadiya (2011) has selected a busy corridor of Ahmedabad city of India for the application of two way coordination methodology. There are six signalized intersections (two are at either end of the corridor and four are at intermediate) including three round-about on 4.6 km long corridor of Navarangpura area (Figure 6). All intersections are spacing less than 1 km. Separate parking space is provided on either side of the road, so there is less possibility of parking the vehicles on the road. Therefore, the whole width of the road can be utilized effectively. The geometrics of the intersections are well defined and good as per design consideration. The visibility is good throughout the road and there is median, which separates the flow from opposing traffic. There are at least two lanes in one direction flow throughout the stretch of a road. Due to the above factors, there is less interference to traffic flow. The author has collected required traffic data like average traffic speed in both directions of each link, classified traffic volume on each intersection for the evening peak period. It reveals heavy traffic on both the directions. Traffic is mainly composed of 2 wheelers, 3 wheelers, cars, buses and non-motorized vehicles. So it is a good situation for applying coordination to signals on selected corridor. The time-space diagrams are prepared in AutoCAD for the existing signal timings and for the different alternatives using two way coordination methodologies. The delay at each intersection is obtained by offset measurement in time-space diagrams. In comparison with existing signal timings, adopted two way coordination methodology gives 30 to 60% reduction in over all delay on the selected corridor.

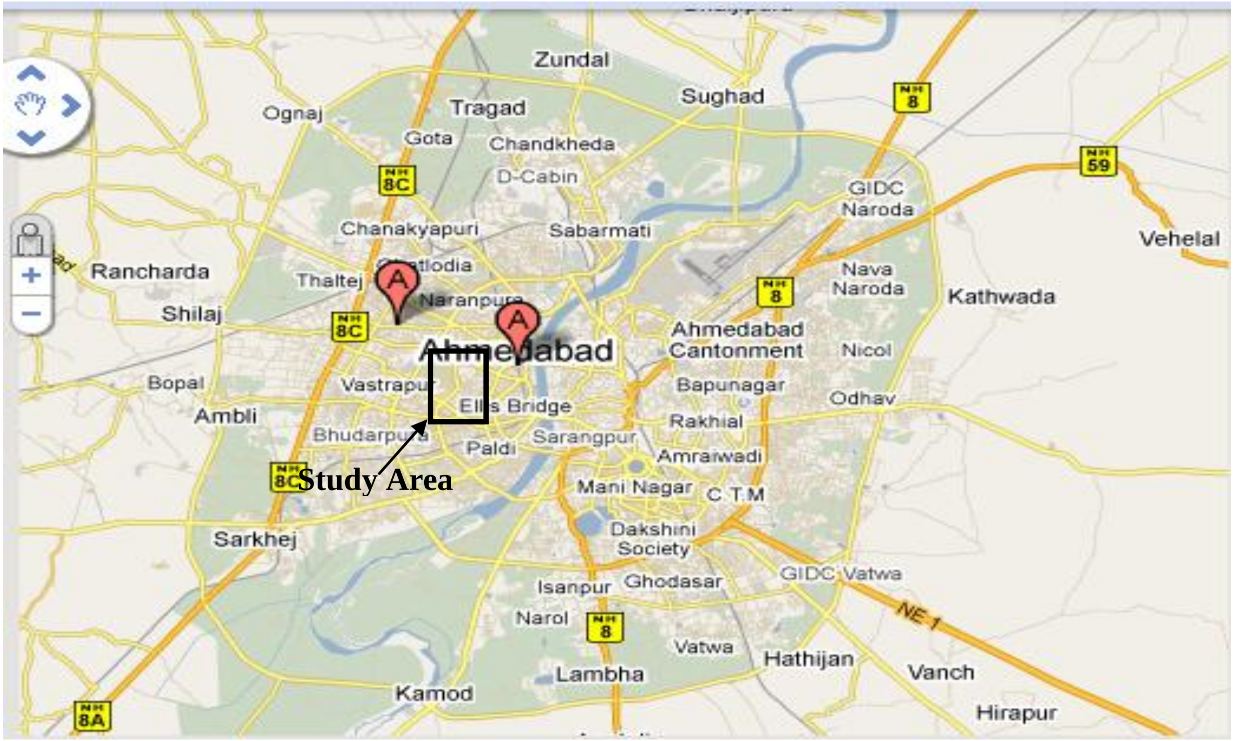


Figure 6: Location of study area for two way coordination

5. Adopted methodology for four way signal coordination

Now, it is interesting to analyze that whether these plans are suitable for the four-way signal coordination or not? Patel (2011) has studied about the different strategies adopted for the four way signal coordination. A set of four intersections is analyzed for the coordination (Figure 7). Mainly the right turners moving in clockwise direction require four way signal coordination for reducing delay. For the any quadrilateral, each side may have odd or even phase difference. This gives different situations for the quadrilateral, like (Odd, Odd, Odd, Odd) or (Even, Even, Even, Even) and so on. There are 16 possibilities (4 x 4 =16) for the combinations. Out of which following 8 situations do not satisfy the phase plans suggested as per the Table 3.

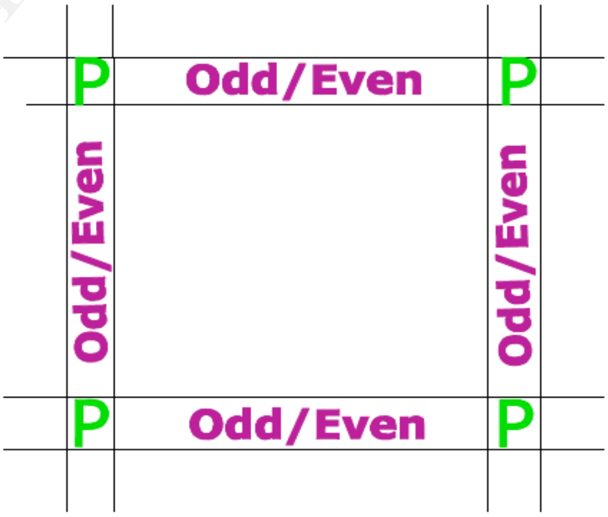


Figure 7: Four way Coordination and different phase possibilities.

The problematic situations are shown below as 4 sets, where O = Odd and E = Even phase difference.

(1) (O, E, E, E) and (E, O, O, O)
(2) (E, E, E, O) and (O, O, O, E)
(3) (E, O, E, E) and (O, E, O, O)
(4) (E, E, O, E) and (O, O, E, O)

As shown above in section 3, the two way coordination methodology of Phase Plan A and Phase Plan B (Figure 3) cannot satisfy above four difficult situations. For example, 2 problematic situations (E, O, O, O) and (O, E, E, E) are shown in Figure 8.

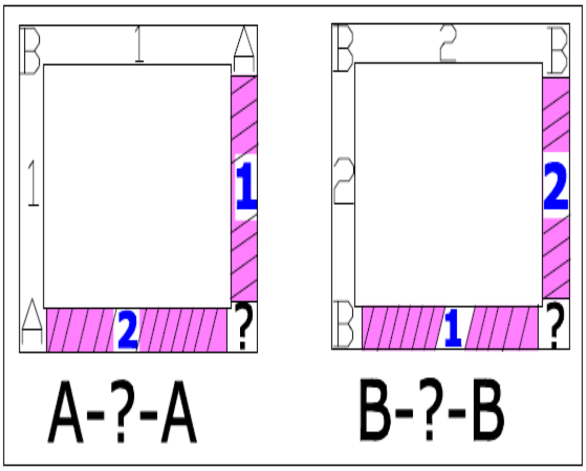
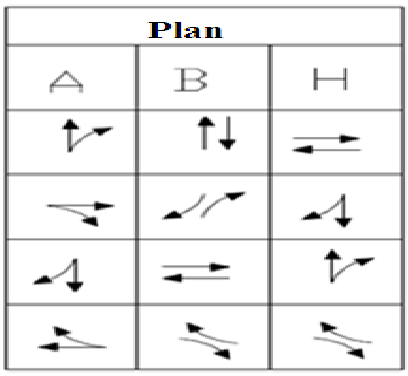


Figure 8: Problematic Situations

Table 4 shows that for the (E, O, O, O) situation shown in Figure 8, A-A-A plans and A-B-A plans give an average delay of 75 sec and 30 sec respectively. Similarly for the (O, E, E, E) situation shown in Figure 8, B-A-B plans and B-B-B plans give an average delay of 67.5 sec and 67.5 sec respectively. In this condition, a hybrid phase plan H is designed (Table 4), which is giving an average delay of 30 sec and 60 sec in the A-H-A and B-H-B plans respectively. In the similar way, plan H can be implemented suitably to rest of the 6 problematic situations, which can give lesser delay compared to the plans A and B.

Table 4: Hybrid phase plan and delay time



Delay Time			
A-?-A		B-?-B	
? =	Delay in sec	? =	Delay in sec
A	75	A	67.5
B	30	B	67.5
H	30	H	60

For the above odd and even phase differences Overall combined delay for the forward and backward directions of R to R, R to S, S to R and S to S is obtained and given in Table 5.

Table 5: Overall combined delay in sec for the phase plans A, B and H

Plan	Phase	
	Odd	**Even**
A-A	270	60
A-B	105	240
A-H	240	105
B-B	270	150
B-H	225	210
H-H	210	230

6. Application of four way coordination methodology

For the study of four way coordination of traffic signals, a small network (quadrilateral) with closely spaced signalized intersections is selected near Navrangpura area of Ahmedabad city of India (Patel, 2011). In the selected quadrilateral network, 3 intersections are four armed and signalized, whereas fourth intersection is six arm round about without traffic signal. An ideal quadrilateral, which is having all four junctions with four arms and signal control has not been found during the study. Figure 9 shows the selected quadrilateral, in which No.1 - Swastik junction, No.2 - Girish coldrinks junction, and No.3 - Navrangpura bus stop junction are situated. These are signalized and four armed junctions. No.4 is Mithakhali junction (round about) which is having six approaches without traffic signal control. Classified traffic volume counts, spot speed study and stopped delay study at intersection have been carried out during evening peak hours.

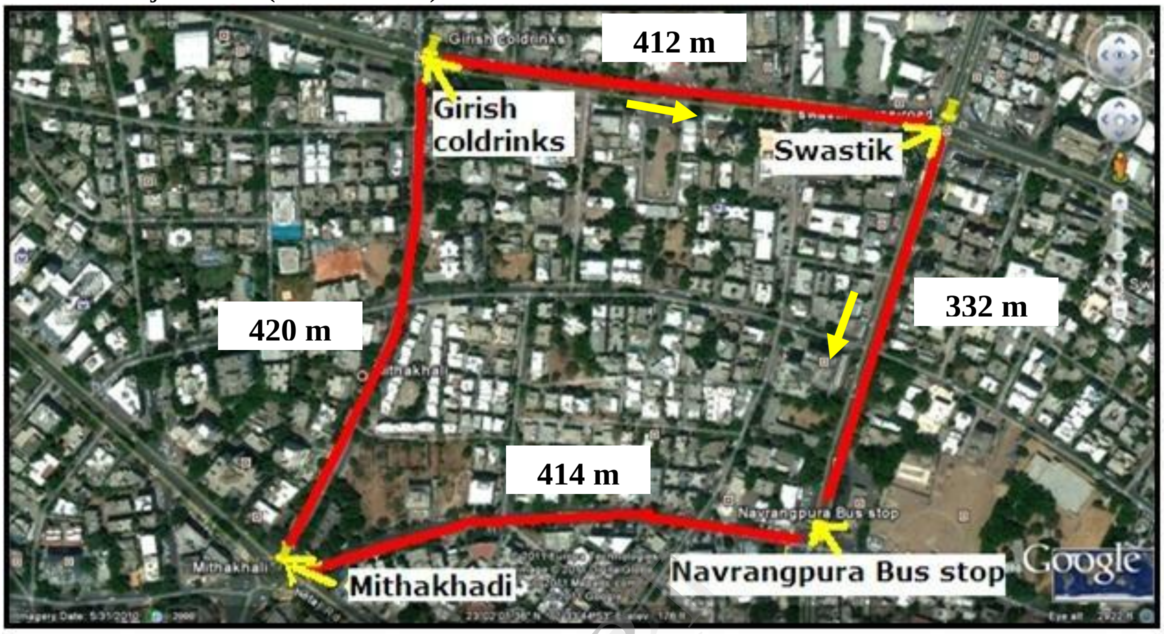


Figure 9: Location of study area for four way coordination.

The time-space diagrams are prepared in AutoCAD for the existing signal timings and for the different alternatives using four way coordination methodologies for the traffic movements from Girish Coldrinks intersection to Swastik intersection and from Swastik intersection to Navrangpura Bus stop intersection (clockwise right turning movement between signalized intersections). The delay at each intersection is obtained by offset measurement in time-space diagrams, as well as stopped delay is also measured on the intersections. A good linear relationship between AutoCAD delay and observed stopped delay on the field for the existing signal conditions has been established. R^2 values ranging from 0.902 to 0.922 have been obtained, which shows good linearity. Applying the proposed methodology of four way coordination of signals on the selected network, overall delay obtained in AutoCAD is reduced about 45% to 65% compared to the existing signal system. The predicted stopped delay is reduced about 52% for the proposed four way coordinated signal system, compared to the existing signal system.

7. Findings from methodology

- ❖ For the traffic signal coordination, equal cycle time shall be selected on every intersection to minimize the overall delay. The cycle time can be adopted as an average of designed cycle time of the intersections on the network level.
- ❖ Equal phase timings and proper selection of phase sequence can reduce

delay considerably in signal coordination.

- For the closer intersections, shorter cycle is more beneficial for quicker traffic movement and to eliminate the possible spillage of queues on up-stream intersections.

- For the different phase offsets, different phase plan strategy can reduce delay considerably in signal coordination. For the odd phase differences use phase plan A vs. B and for even phase differences use phase plan A vs. A. When the situation cannot be solved by this strategy in four way coordination at network level, then phase plan H can be considered.

- The above-mentioned methodology is best suitable for the pre-timed signals on busy corridor for the signal coordination. It can reduce about 30% travel time of the vehicles. For its implementation, there is no need of extra cost of soft-wares, sensors and other arrangements. This methodology can be easily adoptable to Indian traffic conditions.

8. Limitations of both methodologies

- Pedestrian counts are not carried out in this study.
- Traffic influence from the intermediate minor streets is neglected.
- Any simulation software is not used for the different alternatives.
- Logic for the optimum phase offsets is not developed to incorporate in time-space diagram for delay calculation. However, phase offsets are optimized by trial and error method in AutoCAD.
- Real implementation of proposed methodology could not be done on the field.

9. Proposed Novel Approach

Here, both the studies are done for evening peak period. But it should be extended for morning peak period as well as for off-peak period, as traffic flow and their average journey times differs at different time of the day. Coordination of signals in the present case study has been done by adopted methodology, but it can be done more effectively by using various soft-wares such as TRANSYT, SCOOT, VISSIM, Synchro, etc. The traffic signal coordination may be carried out by low cost sensors system and centralized control. The plan of signal coordination should be upgraded from time to time to suit for various changes such as, change in traffic flow, change in average journey time, change in geometrics, etc.

Coordination between signals in the above studies is based upon manually calculated time-space diagrams, and no prior computerized optimization process took place. The establishment of effective green waves through several intersections considering Time-of- day (TOD) intervals will be the primary objective of the ongoing research. Presently a mathematical formulation is in progress to find the delay of vehicle between two consecutive intersections for the different phase timings, phase plans, phase sequences and phase off sets. The study aims to incorporate developed formula in to some sort of programming language. After running the programme, it is possible to find delay for the different situations and based on that optimum signal cycle parameters can be found for the coordination. This signal cycle parameters can be cross examined by simulation soft-wares like VISSIM, PARAMICS, TRANSYT-7F, SYNCHRO etc.

The Disutility Index (DI) is a combination of vehicle delay, stops, and fuel consumption. (mahmood mahmoodi nesheli et.al. 2009). Weighting factors are available in order to place more emphasis on any of these three DI components if desired. Delay-only optimization results in excessive stops and fuel consumption. Minimization of Excess fuel consumption is considered to be a good compromise between bandwidth and delay-based optimization. Although the DI has been shown over the years to be a practical and effective combination of minimizing delay and stops, it does not necessarily produce a wide bandwidth. In this ongoing research it has been proposed to find the disutility index (DI) of the selected corridors and tries to correlate disutility index and optimum signal setting time of the selected junction which in turn gives minimum delay. Also, it would be interesting to compare the delay occurred by providing Adaptive Traffic Control Signals acting independently (isolated) on each signalized intersection of the corridor and the delay occurred by two-way coordination of pre-timed traffic signals.

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