DEVELOPMENT OF MODEL FOR PRE-TIMED TRAFFIC SIGNAL COORDINATION ON URBAN ROAD CORRIDOR

Ph.D. Synopsis

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Development of Model for Pre-Timed Traffic Signal Coordination on Urban Road Corridor

1. Abstract

The nature of traffic flow and movement condition in India is quite different than other developed countries. Indian traffic has mixed vehicle flow and it operate with Left Hand Traffic (LHT) having Right Hand Drive (RHD). Highway Capacity Manual (HCM) is indispensable resource for proper planning, design and operation of road traffic facilities. Traffic Congestion on major corridor consequent upon existing lacuna in signal control strategy is a major problem in Ahmedabad city. To contend the situation this research is carried out to design the efficient signal control technique for two-way coordination. C G Road was identified as a troubled corridor during reconnaissance survey and as such, selected for study. If busy urban arterial is having four arm signalized intersections in series with constant spacing, then two-way coordination of pre-timed traffic signals can be achieved by alternative or double alternative or simultaneously progressive system. However when the busy urban arterial is having signalized intersections of diverse number of approaches and different spacing between each other, then the methodology other than traditional progressive system needs to be worked out. In this research a methodology is developed for the two-way coordination of pre-timed signal for 3 arm, 4 arm and 5 arm intersections for all probable six cases considering five important parameters i.e. travel time, link distance, Saturation Flow Rate (SFR), Demand Flow Rate (DFR) and width of approach. After scrutinizing several permutations and combination of phase plan and phase sequence on graph paper, nine different phase plans (five for 4 arm, and two each for 3 arm and 5 arm intersection) have been prepared to solve two-way traffic signal coordination problem with different travel time situation. Finest possible arrangement of phase plan, phase offsets and phase sequence with all probable groupings of 3 arm, 4 arm and 5 arm intersections have been worked out and presented in tabular format (table 1). Then after main emphasis of the research is devoted to evolve robust signal coordination model for commonly available four arm signalized intersection.

Optimization of signal control plan include decision of optimal cycle length, green split, phase plan and offset. After deciding phase sequence and phase plan, for other three signal control parameters robust model is developed to calculate cycle length, green split (phase length) and phase offset to provide proper two-way coordination. Traffic researchers across the world assumes
common travel time in both direction to arrive at common cycle length mandatory for signal coordination. The model (Methodology 1) described here also works on the same assumption. Later on an attempt has been made to relax this assumption and proposed a model (Methodology 2) to derive cycle length when travel time in outbound and inbound direction is different. For the selected corridor this study has derived dynamic Passenger Car Unit (PCU) values for the observed traffic flow at selected intersection. Apart from this the study has derived relationship for actual travel time and travel time by space mean speed. Efforts have also been made to correlate observed stopped delay and delay obtained by time space diagram. Considering the vital importance of SFR and practical difficulty to accurately estimate the SFR, after exploring available past literature on SFR values for Indian condition the study had proposed “low” SFR values and “high” SFR values that can be conveniently used to compute capacity of the intersection approach.

2. Brief Description on the state of the art of the research topic

A traffic signal is a device that allows traffic engineers to leave their intelligence at an intersection to operate it in their absence. In view of the ever increasing traffic congestion and lack of possibilities for infrastructure expansion in urban road networks due to space limitation and other constraint, the importance of efficient signal control strategies, particularly under saturated traffic conditions, can hardly be overemphasized. For developing effective signal coordination strategy four signal control parameters i.e. cycle length, green split (phase length), phase sequence and offset are to be obtained carefully. Phase plan and sequence are to be fixed in such a way so every legal movement of the phase should receive green during every signal cycle. Other three parameter of the signal control is govern by link distance, travel time, SFR, DFR and width of approach. While link distance and approach width does not change over time the remaining three variable are changing several times in a day. SFR is perhaps the most important parameter in signalized intersection control strategy. Despite its central importance it is extremely difficult to accurately measure SFR at current stage of research. Even the HCM suggests eleven different adjustment factors to estimate SFR and gives default value of 1900 pcu/hr/ln. Indian Road Congress (IRC) in its Special Publicaton (SP)-41(IRC 1994) suggest empirical formula \(525w\) to estimate SFR. Selection of PCU values and availability of continuous one hour green signal as well as saturation condition makes task of calculating exact SFR insurmountable.
To obtain the optimum cycle length and green splits, any of the available methods like, Webster’s formula (1958), Australian Road Capacity Guide Method (ITE, 1982), Highway Capacity Manual Method (2010) is being used generally. These methods are good enough for isolated intersections. (Varia et al., 2013). IRC 93-1985 provide guideline about signal cycle time determination based on Webster’s methodology which fails to give optimum signal cycle time for near saturated or saturated condition. It must be noted, however, that it is virtually impossible to develop a complete and final signal timing that will not be subject to subsequent fine-tuning when the proposed design is analyzed using the HCM 2010 analysis model or some other analysis model or simulation. This is because no straightforward signal design and timing process can hope to include and fully address all of the potential complexities that may exist in any given situation. (Roess et al., 2011). Offsets are also a very sensitive timing parameter the wrong selection of an offset at one intersection can affect the delay of the whole arterial system. (HCM 2010)

Morgan and Little (1964) are the pioneers who first presented a model to maximize the total two-way progression bandwidth on an arterial. Following the same principle, Little (1966) further proposed an advanced model to concurrently optimize the common cycle length, progression speeds, and offsets with integer programming. Purdy (1967) has given methodology for two way coordination applying bandwidth concept. Kadiya and Varia (2010) are the first who presented a methodology to coordinate the signals for four arm intersections in two-way directions on the busy urban corridor for typical Indian condition. They have presented phase plan to achieve the goal of coordination. There are mainly two kinds of algorithms for offset optimization. One kind focuses on progression bandwidth optimization along arterials, including PASSER (Messer et al., 1974), MAXBAND (Little et al., 1981) and MULTIBAND (Gartner et al., 1990). The other kind focuses on minimizing system delay, including TRANSYT (Robertson, 1967) and Synchro (Traffic ware, 2001). However, current practice for offset design focus either on progression quality for coordinated phases or green time occupancy and most of them are designed to improve the efficiency of one main direction. The effectiveness of all progression-based models, in general, are conditioned on the common traffic pattern where through traffic constitutes the primary volume on the arterial, and consequently turning flows are not the main concern of the signal. (Yang et al., 2015). Recent study on offset optimization advocates use of longest cycle length from entire arterial as common cycle length for coordination. (Lan and Chang. 2016).
After advancement in computer technology and computing efficiency various online signal optimization software’s are also developed. These software’s are not relevant in Indian mixed traffic condition where prevailing roadway and traffic condition are quite different. (Arasan and Koshy. 2005) 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 (Roess et al., 2011). It is very difficult or impossible to include traffic heterogeneity and limited lane discipline into control model for field implementation (Nuli and Mathew. 2013). In online signal optimization, the signal offset cannot be reset frequently, because the adjustment of the offset requires several cycles. (Cui et al., 2017)

Despite the aforementioned research accomplishment in signal control by traffic researchers, most of those studies, developed mainly for arterials with passenger car flows, suffer inevitable deficiencies if applied directly to the traffic flow comprising mixed vehicular flow. In summary, a few studies are available pertaining to pre-timed two-way traffic signal coordination, in mixed traffic condition having LHT with RHD. Owing to limitations of the online signal coordination methods there is a need to develop simple and lucid method of signal coordination which can be easily implemented. The research strive to develop robust signal optimization model which can simultaneously optimize all four signal control parameters.

3. Definition of the problem

Development of signal coordination technique for typical Indian condition is the central focus of this research. India which is home of around 1.3 billion people and 32% urban population (Census 2011) is presently fastest developing major economy in the world. India will experience exponential growth in vehicle ownership and urbanization in near future. The limitation of available road space in Indian cities is a matter of great concern. For optimal use of available road space and safety of road users the efficient signal control strategy can prove beneficial. In view of limited research and few standardized guidelines and codes available for signal control and analysis, traffic researches and planners across India are working overnight to develop first ever Indo- HCM under the umbrella organization Central Road Research Institute (CRRI), India. Traffic researchers across the world develop signal coordination technique without considering whether it is require or not. Link distance, speed between intersection and volume to capacity ration of each approach need to ascertain before applying the coordination. Offset optimization in
all progression-based models, in general, are conditioned on the common traffic pattern where through traffic constitutes the primary volume on the arterial, and consequently turning flows are not the main concern of the signal. While balanced split provide more equitable green time for all traffic movements thus reducing potential for unsafe operations of “unfairly treated” traffic movements. Presently no signal optimization software is available to simultaneously optimize all four signal control parameters for Indian condition.

To address the problem of “coordination ability” factor of the links and derive optimal signal coordination plan employing simultaneous optimization of all four signal control variables in a generalized model are necessary to elucidate the signal optimization problem.

4. Objective and scope of work

The scope of the research work is to develop a methodology for the two-way coordination of pre-timed signal for 3 arm, 4 arm and 5 arm intersections for all probable six cases considering travel time and link distance between two intersections. After developing coordination scheme of the intersections having different numbers of approaches for all six combinations, the main emphasis of the research then after devoted to evolve robust signal coordination methodology for commonly available four arm signalized intersection. Considering the focus of the research the main objective of the research are:

- To derive robust methodology for two-way coordination of traffic signal which can optimize all four signal control parameters simultaneously. (Cycle length, green split, phase sequence and phase offset).
- To develop a model for two-way coordination of pre-timed traffic signal along urban corridor for mixed traffic composition.

5. Original contribution by the thesis

- The research has developed complete logic of signal coordination for all type of intersection with phase plan, phase offset and phase sequence after that it has given robust signal coordination model for 4 arm –vs- 4 arm intersection coordination. As per available information with us this is the one of the first attempt for Indian condition. The proposed simplistic model shall be useful to solve signal coordination problem of resource crunch developing countries like India.
• The study has derived dynamic PCU values and relationship between actual travel time and travel time by space mean speed for selected corridor.

• Incorporating all logic of proposed five Delay Minimization Scheme (DMS) computer program in C language is developed. The developed program improved with Genetic Algorithm (GA) which can be used to find best possible signal cycle length, phase sequence and phase length (green split) for effective two-way coordination with minimum delay along corridor.

• For its implementation, there is no need of extra cost of soft-wares, sensors, technical manpower, huge data collection it’s processing and extensive computational efforts. The model works in offline mode which provide immunity from possible theft and hacking of online data.

6. Methodology of Research, Result/ Comparison

6.1 Proposed Methodology 1

For two-way signal coordination, it is desirable to adopt an average cycle time of the intersections on 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. For Indian condition where “keep left” rule is followed left turn on red (LTOR) is accepted. Traffic signals are conveniently employed on 3arm, 4arm and 5 arm intersection. Generally more than 5 arm intersection is converted into rotary intersection and it is difficult to set two-way coordination for that. Out of six possible combinations the highest probable and generally available combination i.e. 4 arm -vs- 4 arm is presented here. The research has developed methodology adopting following assumptions.

• During the analysis time, average traffic stream speed in both directions remains same.

• 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.

• Phase length \( P_l \) 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.
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. \(2n\), where \(n = 1, 2, 3, \ldots\)), 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,

\[
tt = \frac{d}{v} \ldots (1)
\]

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,

Phase offset \((Po)\) = travel time \((tt)\) = \(Pl \times 2n \ldots (2)\)

\[\text{Figure 1: Two-way coordination for even phase difference (4 arm-vs-4 arm intersection)}\]
Therefore, phase length \((Pl) = \frac{tt}{2n}\) \(\ldots \) (3) (where \(n = 1, 2, 3 \ldots\))

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

As per IRC 93-1985 pedestrian green requirement \(g_{min} = 16\) 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 16 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. \(Pl = \frac{tt}{2x}\) (when, \(tt \geq 2g_{min}\)) \(\ldots\) (3)

2. \(Pl = tt\) (when, \(g_{min} \leq tt < 2g_{min}\)) \(\ldots\) (4)

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

\[C = 4Pl\] \(\ldots\) (5)

Figure 2: Two-way coordination for odd phase difference (4 arm-vs- 4 arm intersection)

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 reveals 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 phase 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 having details of two-way coordination method.

Table 1: Details of two-way coordination for selected combination

<table>
<thead>
<tr>
<th>Combination (Left-vs-Right)</th>
<th>Situation (Phase difference)</th>
<th>Type of Phase Plan</th>
<th>Cycle time</th>
<th>Required phase offset for major street flow</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Forward direction</td>
</tr>
<tr>
<td>4arm-vs-4arm</td>
<td>Even</td>
<td>A</td>
<td>A</td>
<td>4Pl</td>
</tr>
<tr>
<td></td>
<td>Odd</td>
<td>A1</td>
<td>A2</td>
<td>4Pl</td>
</tr>
<tr>
<td>3arm-vs-3arm</td>
<td>Even</td>
<td>B</td>
<td>B</td>
<td>3Pl</td>
</tr>
<tr>
<td></td>
<td>Odd</td>
<td>B1</td>
<td>B1</td>
<td>3Pl</td>
</tr>
<tr>
<td>3arm-vs-4arm</td>
<td>Even</td>
<td>B</td>
<td>A</td>
<td>4Pl</td>
</tr>
<tr>
<td></td>
<td>Odd</td>
<td>B1</td>
<td>A2</td>
<td>4Pl</td>
</tr>
<tr>
<td>3arm-vs-5arm</td>
<td>Even</td>
<td>B1</td>
<td>C</td>
<td>2.5Pl</td>
</tr>
<tr>
<td></td>
<td>Odd</td>
<td>B1</td>
<td>C</td>
<td>2.5Pl</td>
</tr>
<tr>
<td>4arm-vs-5arm</td>
<td>Even</td>
<td>A</td>
<td>C</td>
<td>5Pl</td>
</tr>
<tr>
<td></td>
<td>Odd</td>
<td>A1</td>
<td>C1</td>
<td>5Pl</td>
</tr>
<tr>
<td>5 arm-vs-5arm</td>
<td>Even</td>
<td>C</td>
<td>C</td>
<td>5Pl</td>
</tr>
<tr>
<td></td>
<td>Odd</td>
<td>C1</td>
<td>C1</td>
<td>5Pl</td>
</tr>
</tbody>
</table>
6.2 Proposed Methodology 2

The methodology 1 has been derived based on the same notion that average travel time in both (outbound and inbound) direction and phase time of all phases at intersection is equal. This implies that approach demand i.e. DFR at all approach and travel speed of traffic stream in both direction is equal. In reality there are every possibility that DFR at approach as well as travel time is varying. To overcome this difficulty in two-way coordination here we elaborate simplistic model for deriving cycle time for effective two way coordination. Apart from the identical situation case discussed above this condition leads to two more cases for coordination.

1. When travel time in forward direction $t_{ij}$ and travel time in backward direction $t_{ji}$ is different.

2. When travel time as well as phase time is different.
Let, considering the figure 4 we have,

t_{ij} = Travel Time of traffic stream between intersection i to j

\( t_{ji} \) = Travel Time of traffic stream between intersection j to i

\( C_i \) = Cycle Time for two way coordination at intersection i

\( \alpha_i, \alpha_j \) = start of green for phase at intersection i and j

\( \beta_i, \beta_j \) = end of green for phase at intersection i and j

\( P_i, P_j \) = Respective Phase time at intersection i

Here considering the figure and applying ideal offset concept used for two-way coordination, Starting time of phase 1 at intersection j would be,

\[
\alpha_{1j} = \alpha_{1i} + t_{ij} \quad \ldots \ldots \ (6)
\]

Similarly, Starting time of phase 3 at intersection i would be

\[
\alpha_{3i} = \alpha_{3j} + t_{ji} \quad \ldots \ldots \ (7)
\]
Similarly, End time of phase 4 at intersection \( i \) would be,

\[
\beta_{4i} = \beta_{4j} + t t_{ji} \quad \ldots \ldots (8)
\]

Considering initial offset of 0 second at both intersection, from equation 6 we have,

\[
\alpha_{1j} = t t_{ij} \quad \ldots \ldots (9)
\]

and from equation 7 we have,

\[
\alpha_{3i} = t t_{ji} \quad \ldots \ldots (10)
\]

Looking to the figure for proper two way coordination between two four arm intersections in direction \( i \) to \( j \) if equation (9) to be satisfied than first two phase movement (in our case \( P_{3j} \) and \( P_{4j} \)) at intersection \( j \) should be completed before the phase movement 1 start at intersection \( j \).

Here as per phase plan first two phase movement at intersection \( j \) is \( P_{3j} \) and \( P_{4j} \)

\[
\therefore \alpha_{1j} = P_{3j} + P_{4j} \quad \ldots \ldots (11)
\]

From equation (9) we have,

\[
\therefore t t_{ij} = P_{3j} + P_{4j} \quad \ldots \ldots (12)
\]

Similarly, as per the figure for proper two way coordination between two four arm intersections in direction \( j \) to \( i \) if equation (10) to be satisfied than first two phase movement (here \( P_{1i} \) and \( P_{2i} \)) should be completed before the phase movement \( P_{3i} \) start at intersection \( i \).

Here as per phase plan first two phase movement at intersection \( i \) is \( P_{1i} \) and \( P_{2i} \)

\[
\therefore \alpha_{3i} = P_{1i} + P_{2i} \quad \ldots \ldots (13)
\]

From equation (5) we have,

\[
\therefore t t_{ji} = P_{1i} + P_{2i} \quad \ldots \ldots (14)
\]

Cycle time at intersection \( i \) will be,

\[
C_i = P_{1i} + P_{2i} + P_{3i} + P_{4i} \quad \ldots \ldots (15)
\]
Placing value of equation (14) in equation (15)

\[ C_i = t t_{ji} + P_{3i} + P_{4i} \ldots (16) \]

Now, for successful two way coordination end time of last phase 4 at intersection \( i \)

\[ \beta_{4i} = t t_{ji} + P_{3i} + P_{4i} \ldots (17) \]

Considering initial 0 second offset, from the equation (8), (11) & (12) phase completion time of phase 4 at intersection \( j \)

\[ \beta_{4j} = \alpha_{1j} = t t_{ij} \ldots (18) \]

For effective two way coordination applying value of equation (18) in to equation (8) the phase completion time of last phase 4 at intersection \( i \)

\[ \therefore \beta_{4i} = \alpha_{1j} + t t_{ji} = t t_{ij} + t t_{ji} \ldots (19) \]

\[ \therefore C_i = t t_{ij} + t t_{ji} \ldots (20) \]

6.3 Genetic Algorithm Approach:

30 cycles of the collected data is analyzed and volume data has been extracted from videography by manual counting. The one hour flow as per IRC PCU values range from min 1950 pcu/hr/approach from mithakhadi six road at Girish intersection to max 2179 pcu/hr/approach from Navrangpura bus stand at Swastik intersection. Similarly one hour flow as per Dynamic PCU values derived specifically for selected corridor range from min 1258 pcu/hr/approach from mithakhadi six road at Girish intersection to max 1646 pcu/hr/approach from Navrangpura bus stand at Swastik intersection. The variation in flow is 20% as per IRC PCU values but it is more than 30% as per Dynamic PCU values. The obtained flow values for major and minor approach has inspired to rethink the strategy of equal phase time for all approach of intersection accordingly GA is employed to check whether change in phase time can be successful to further reduce the overall corridor delay.

To achieve the objective of the model to minimize overall total delay we apply constraint of min green time as per IRC to the right turning (odd phase) movement of the both intersection. Here,
\( G_{ip}^{min} \) = min green time for phase p of intersection i

\( G_{ip} \) = green time for phase p of intersection i for the given time period t

\( P_{ik} \) = Number of phase k at intersection i (k=1, 2… n)

\( tt_{ij} \) = travel time from i to j

\( tt_{ji} \) = travel time from j to i

\( \varphi_{ij} \) = Right Turner delay from i to j

\( \varphi_{ji} \) = Right Turner delay from j to i

\( \psi_{ij} \) = Straight Movers delay from i to j

\( \psi_{ji} \) = Straight Movers delay from j to i

The general form of optimization model with GA would be,

\[
\min Z(f) = \sum (\varphi_{ij} + \varphi_{ji} + \psi_{ij} + \psi_{ji}) \quad (21)
\]

Subject to the constraints

\[
C_{min} \geq \sum_{p \in P_n} G_{ip}^{min} \quad (22)
\]

\[
C_{min} \geq \{ tt_{ij}^{min} + tt_{ji}^{min} \} \quad (23)
\]

\[
C_{max} \leq \{ tt_{ij}^{max} + tt_{ji}^{max} \} \quad (24)
\]

\[
G_{ip} \geq G_{ip}^{min} \quad (25)
\]

\[
P_1 + P_2 = tt_{ji} \quad (26)
\]

\[
P_3 + P_4 = tt_{ij} \quad (27)
\]

The above function is non-linear and non-convex, that makes it difficult to differentiate and to obtain the global minimum using analytical methods. In this study, minimization of the above objective function is carried out by deciding signal setting parameters by a GA optimizer. The LibGA software (version 1.00, developed at the Massachusetts Institute of Technology, USA) is used for GA application. Green times and phase sequences of signalized intersections can be decided by GA optimizer to minimize the values of objective functions. The figure 5 explain overall methodology in flow chart.
Input Data: Excel Sheet with Existing No. of Intersections, Phase time, Phase sequence, Starting Phase, Distance & Speed between Link, Demand Flow Rate

Check: Coordination criteria
Link length, Speed & v/c ratio

Yes

Check: Phase plan & sequence as per developed methodology

No

Change it as per developed methodology

Start

No

Coordination is not advisable

Yes

DMS 1: Change of phase plan
If, \( tt \geq 2 g_{\text{min}} \), Select Plan A
If, \( g_{\text{min}} \leq tt < 2 g_{\text{min}} \)
Plan A1,A2,Z & Z1

DMS 2: \( C_{\text{opt}} \) with proportionate phase length
\( C_{\text{opt.}} = \text{Avg. cycle length of all intersections} \)
\( Pl = \text{proportion of each phase in existing cycle} \)

DMS 3: \( C_{\text{opt.}} \) with equal phase length
\( Pl = \frac{tt}{2n} \) (when, \( tt \geq 2 g_{\text{min}} \))
\( Pl = tt \) (when, \( g_{\text{min}} \leq tt < 2 g_{\text{min}} \))
\( C = 4Pl (Pl = \text{max} \frac{tt}{2n}) \)

DMS 4: \( C_{\text{opt.}} \) with \( P_1 + P_2 = tt_{ji} \) and \( P_3 + P_4 = tt_{ij} \)
\( C_{\text{opt.}} = \text{addition of avg. value of } tt_{ij} \& tt_{ji} \)

DMS 5: \( C_{\text{opt.}} \) with \( P_1 + P_2 = tt_{ji} \) and \( P_3 + P_4 = tt_{ij} \)
\( C_{\text{opt.}} = \text{addition of max value of } tt_{ij} \& tt_{ji} \)

Output: \( C_{\text{opt.}} \) and phase length having minimum overall corridor delay

Optimization of signal plan with Lib GA optimizer: for adjusting the odd phases up to \( g_{\text{min}} \) range and existing demand

GA output with \( C_{\text{opt.}} \) and phase length having minimum overall corridor delay

Stop

Figure 5: Flow chart of Signal Coordination Model for minimum corridor delay
6.4 Model Validation Results:

To validate the above developed model 1 afternoon peak data and evening peak data has been analyzed. For afternoon peak the delay calculation is performed by time space diagram for nearly 10 consecutive cycle. Reduction in delay for three Delay Minimization Scheme (DMS) based on model 1 is observed and it is presented in fig. 6. Here reduction of around 4% total delay is observed in DMS 1 which validate our developed phase plan and phase sequence. Similarly DMS 2 which validate “existing” demand responsive phase time and equal cycle length and DMS 3 are validated which reduces delay by 73.7% and 75.9 % respectively. For evening peak data delay is calculated for nearly 6 cycle and results are presented in fig 7. Here reduction of delay is observed by 11.6% for the DMS1 while it is 79% for DMS 2 &3. Figure 8 shows model validation and comparison of delay which is calculated applying “optimized” signal setting from DMS 4 & 5 and “optimized” signal setting with GA for one cycle. The GA is effective for reducing delay up to 31%. Table 2 is presented with the comparison “existing” and “optimized” signal timing parameters for C G Road area of Ahmedabad, India.

Table: 2 “Existing” and “Optimized” signal timing parameter for C G Road area, Ahmedabad

<table>
<thead>
<tr>
<th>&quot;Existing&quot; signal setting</th>
<th>&quot; Optimized&quot; Signal setting</th>
<th>By DMS 1 to 3</th>
<th>By DMS 4, 5</th>
<th>By Applying GA</th>
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<tbody>
<tr>
<td>Z</td>
<td>C</td>
<td>P</td>
<td>T</td>
<td>M</td>
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<td>1</td>
<td>33</td>
<td>Anti-Clockwise</td>
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<td>27</td>
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</table>

Z= Intersection code, C= Cycle time(sec) , P= phase number, T= Time of phase (sec) ,M=phase sequence
Figure 6: Validation of model 1 (Delay in sec)

Figure 7: Validation of model 1 (Delay in sec)

Figure 8: Validation of model 2 (Delay in sec)
7. Achievements with respect to objective

- The research has proposed robust technique for two-way coordination of the traffic signal along urban road corridor considering peculiar traffic condition prevailing in India having Right Hand Drive (RHD) with Left Hand Traffic (LHT).
- “Coordination ability” factor proposed in the research is a vital tool for decision makers whether to opt for signal coordination or continue with the present approach.
- For ideal condition of equal phase length and equal demand we proposed two-way signal coordination methodology for all practically possible combination of signalized intersection.
- After scrutinizing numerous permutation and combination of phase plan, phase sequence and phase group on graph paper nine (five for 4 arm intersection and two each for 3 arm and 5 arm intersection) different phase plan with suitable phase offset has been prepared to optimize the phase sequence and phase grouping of the signal control.
- The developed phase plan, phase sequence and model, is validated on the real corridor traffic data of Ahmedabad city. Both afternoon and evening peak data has been analyzed and existing condition is optimized with reduction in delay is observed in both condition.
- To cater the difficulty of measuring SFR for every approach, after exploring past literature particularly for Indian condition, the research has given two different condition of “low” SFR and “high” SFR along with graphs to find SFR of the approach.
- The proposed model with its result is officially communicated to concern traffic authority of Ahmedabad Municipal Corporation, Gujarat, India for its actual implementation.
- Proposed phase plan and phase offset not only useful for corridor optimization but also it has potential to accommodate the need of network level coordination.

8. Conclusion

- Three models for two-way signal coordination of four arm intersection are proposed in this research.
- Clock wise movement of phase is beneficial for reduction in delay along corridor as well as equitable distribution of delay across the cycles thus eliminating the possibilities of individual cycle failure. Clockwise progression and phase group proposed in the research has potential to cater need of network level coordination.
Validation efforts of proposed model 1 (for equal demand and same travel time) reveals that from proposed three Delay Minimization Scheme (DMS), DMS 3 is giving the minimum overall corridor delay with delay reduction of 75.9% for afternoon peak and 79% reduction for evening peak, so it can be concluded that common cycle length with equal phase length at all intersection of corridor may be selected for signal optimization.

Validation efforts of proposed model 2 (for equal demand and variable travel time) unveils that from proposed five Delay Minimization Scheme (DMS), DMS 5 is giving the minimum overall corridor delay so it can be concluded that longest cycle length from the corridor in general may be selected for signal optimization.

Validation efforts for GA based approach (for variable demand and variable travel time) exhibits that Genetic Algorithm (GA) based optimization technique outperform the traditional DMS. When DFR of major approach and minor approach is varying the GA gives optimal cycle length and phase length which is capable to reduce overall corridor delay by 31%.

9. Details of paper publication arising from the thesis


Sisodiya Dharmendra, Shah P. M., Varia H.R. (2016) “Determination of Relationship between Space Mean Speed and Actual Travel Time of a Link between Signalized Intersections.” Published in IJAERD Journal Vol. 3 issue 05, May 2016, ISSN 2348-6406


10. Patents (if any)
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11. References


