Variable-Bandwidth Progression Optimization in Traffic Operation

HU Peifeng¹, TIAN Zongzhong¹, YUAN Zhenzhou², JIA Shunping²

¹ Department of Civil & Environmental Engineering, University of Nevada, Reno, NV, USA 89557
² School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China

Abstract: Attempts are often made to find an optimal coordinated control plan for a group of traffic signals in urban areas, such that platoons of vehicles can proceed through a continuous series of green lights without stopping, thereby reducing considerable unnecessary delay. One main objective of coordinated control is to provide the maximum bandwidth progression by adjusting the offset and phase sequence pattern for each signalized intersection. Most models and methods currently being used are based on mixed-integer linear programming (MILP), which is a mathematical optimization model originally formulated by Little et al. in 1966. A basic limitation of the MILP is that it adds a large number of complex constraints for traffic control networks. In this paper, a new simple method is introduced for finding the optimization plan of arterial and network control by maximization of variable bandwidth. This method has not any “loop” constraints and a completely new approach compares to the MILP method applied in this field. In addition, the results of two examples this paper provided validity and feasibility of this new approach in real applications of traffic signal coordination control.

Key Words: traffic engineering; traffic control; variable bandwidth progression; offset; NEMA phase sequence pattern

1 Introduction

The main objective of coordinated traffic signal control is to keep traffic progressing in a platoon minimizing delays or stops throughout the signal system. Through proper synchronization of signal timing along arterials or urban networks, coordinated control plans can effectively reduce stops, delays and excessive fuel consumption. Two main methods have been used to achieve this objective. The first is based on total delay minimization in the signal system [1-4], and the other focuses on bandwidth maximization along an arterial [5,6]. Several other researchers have combined the delay minimization and bandwidth maximization models to obtain an optimal solution for coordinated signal systems [7-9]. The methodology presented in this paper achieves an optimal traffic signal control plan by maximizing total weighted bandwidth of the traffic signal system. Thus, the following literature review focuses on research and documents pertaining to bandwidth maximization.

In 1966, Little et al. [5] first presented a mathematical bandwidth maximization model, called the mixed-integer linear program (MILP) model. Their synchronization method produced two possible results: (1) the biggest possible bandwidth of equal size for both directions of an arterial, and (2) favoring one direction of an arterial with a large bandwidth and then finding the best possible bandwidth in the opposite direction, if feasible. Based on this model, Little et al. [10] developed a new model called “MAXBAND” which could yield a global optimal solution, finding cycle time, offsets, and NEMA phase sequence patterns to maximize the weighted combination of the bandwidths in both directions along an arterial. In 1988, Chang et al. [11] extended this model to a new version called “MAXBAND-86” which could optimize multi-arterial networks. Gartner et al. [12] presented an optimization approach for arterial progression that could generate variable bandwidth in which each directional road segment obtained an individually weighted bandwidth for different traffic volume scenarios between intersections. Based on this approach, Stamatiadis and Gartner [6] developed a new model in 1996, called “MULTIBAND-96”, which could optimize all the signal control variables in a network. During
the same period, the Texas Transportation Institute developed “PASSER IV”, a personal computer-based program for optimizing signal timings for arterials and multi-arterial closed-loop networks [13,14]. Currently, many researchers are continuing to research this topic; however, most recent endeavors have tried to improve the efficiency of these models through the help of different mathematical algorithms [15–17]. Particularly, genetic algorithms combined with the MILP are the most popular method of finding the optimal solution for coordinated traffic signal timing plans along arterials or in networks.

This paper presents a new approach to obtain the optimal solution by determining the critical variables of coordinated signal control, such as NEMA phase sequence patterns and offsets. This new approach is easy to follow and can be implemented using common computer programming languages, such as C, C++, Visual Basic, et al. The remainder of this paper is composed of three sections. Following this introduction, the first section introduces the new optimization approach. The second section provides two typical examples to demonstrate the practical applicability of the proposed approach. At last, conclusions are drawn regarding the proposed approach based on the analysis results from the examples.

2 Methodology

Coordinated traffic signal control is a strategy to provide a smooth flow of traffic along arterials and networks, reducing travel times, stops, and delays. Coordinated signal systems operate most efficiently when traffic volumes between adjacent intersections are heavy and signalized intersections are in proximity to each other. When traffic between each signalized intersection can maintain a good platoon structure, coordination of the signals will be more beneficial. In cases where traffic volumes are low and vehicles arrive at a signal randomly, or when signals are sufficiently separated, then coordinated signal control operations may provide few distinct benefits [18].

Time-space diagrams are a commonly used tool to depict the quality of signal timing and progression. A time-space diagram of three intersections is shown in Fig. 1, and the associated NEMA phase sequence patterns are shown in Fig. 2. In Fig. 1, the cycle of each intersection is the same though their green time intervals along arterials are different. Assume outbound direction is from intersection 1 to 3, and inbound direction is the opposite. Bandwidth 12 in Fig. 1, which is the bandwidth between intersection 1 and 2 in the outbound direction, is greater than Bandwidth 23. Additionally, the offset reference point is the end of the barrier on the side street. Thus, the offset of intersection 1 is zero, and the offset of intersection 2 and 3 is shown in Fig. 1. In Fig. 2, four NEMA phase sequences along the arterial are shown clearly, whereas not shown for crossing streets.

1) Cycle length

Cycle length is the total signal time to serve all the signal phases at an intersection, including the green time plus any change interval. The cycle length of each signalized intersection should be equal to (or an exact multiple of) the minimum cycle time of all signals in the coordinated control system.

2) Split of a phase

Within a cycle, split of a phase is the portion of time allocated to each phase at a signalized intersection. In this paper, the split of a phase is measured by seconds and are considered as the effective green time for the phase.

3) NEMA phase sequence pattern

NEMA phase sequences used in this paper are NEMA phase sequences, which employ a “dual ring concurrent” timing process and predetermined phase order to label the operation sequence for each individual movement at the signalized intersection. Fig. 2 indicates the four possible patterns of NEMA phase sequences that are analyzed in this paper.
(4) Offset reference point
The offset reference point is a specified point that creates an association between the local signal clock and the system master clock, which is defined as that point within a cycle in which the local controller’s offset is measured relative to the master clock. In this paper, the offset reference point is defined as a point that the end of barrier on the main street, or the start of any phase (through phase or left phase) in arterial street direction (Fig. 1).

(5) Offset
The term offset that is dependent on the offset reference point, is used for controlling the start time referring to the master controller. The offset ranges from zero to the cycle length of the signalized intersection. Offset is a critical parameter to determine the effect of coordination in signalized intersections (Fig. 1).

(6) Bandwidth
Bandwidth is described as the amount of green time available for vehicles to travel through a system at a determined progression speed. Each direction on the arterial street has its own bandwidth. Bandwidths in the same direction in a street can vary between adjacent signalized intersections. To summarize, there are four principal signal timing parameters for determining the optimal solution of coordinated traffic signal control, which are as follows:

(a) Cycle length.
(b) Green time splits of each phase.
(c) NEMA phase sequence.
(d) Offsets.

This study focuses on determining the optimal NEMA phase sequence pattern and offset of each signalized intersection to achieve the maximum bandwidth. The cycle length and split optimizations are not covered in this study.

2.1 Arterial coordination model
To develop a multi-bandwidth model for an arterial street, the basic objective function and several variables must first be introduced. The basic objective is to find the maximum weighted sum of multi-bandwidth in both directions through finding the offset and NEMA phase sequence pattern of each signalized intersection. A comprehensive search is used for maximizing the objective function in this paper. To consider the problem more generally, assume there are a total of \( N \) signalized intersections with two directions of travel at each intersection. The objective function is defined as:

\[
B = B(O_1, O_2, \ldots, O_N, PS_1, PS_2, \ldots, PS_N) = \sum_{i=1}^{N} k_i \cdot \frac{O_i}{O_{\text{max}}} \cdot \frac{PS_i}{PS_{\text{max}}} - \frac{1}{2} \sum_{i=1}^{N} k_i \cdot \frac{O_i}{O_{\text{max}}} \cdot \frac{PS_i}{PS_{\text{max}}}
\]

where,

\[
B(O_1, O_2, \ldots, O_N, PS_1, PS_2, \ldots, PS_N) = \text{objective function, which is a function of variables: } O_1, O_2, \ldots, O_N, PS_1, PS_2, \ldots, PS_N \text{ (s) and which is the weighted sum of multi-bandwidth in both directions,}
\]

\[
\sum_{i=1}^{N} k_i \cdot \frac{O_i}{O_{\text{max}}} \cdot \frac{PS_i}{PS_{\text{max}}} = \text{weighted sum of multi-bandwidths in outbound direction along the arterial street (s),}
\]

\[
\sum_{i=1}^{N} k_i \cdot \frac{O_i}{O_{\text{max}}} \cdot \frac{PS_i}{PS_{\text{max}}} = \text{weighted sum of multi-bandwidths in inbound direction along the arterial street (s),}
\]

\[
O_i = \text{offset of intersection } i \text{ (s)},
\]

\[
PS_i = \text{NEMA phase sequence pattern at intersection } i \text{, and the value of } PS_i \text{ can only be 1, 2, 3, 4,}
\]

\[
\text{GOBT}_i = \text{effective green time of outbound through movement phase (s),}
\]

\[
\text{GIBL}_i = \text{effective green time of inbound left movement phase (s),}
\]

\[
\text{GIBT}_i = \text{effective green time of inbound through movement phase (s),}
\]

\[
d_{i-1} = \text{distance between intersection } i \text{ and } i+1 \text{ (m),}
\]

\[
s_{i} = \text{average speed of progression along the direction from intersection } i \text{ and } i+1 \text{ (m/s),}
\]

\[
c_{i} = \text{total capacity (or capacity of the through lanes) of an arterial street in the segment between intersection } i \text{ and } i+1 \text{ in outbound direction (veh/h),}
\]

\[
c_{i} = \text{total capacity (or capacity of the through lanes) of an arterial street in the segment between intersection } i \text{ and } i+1 \text{ in inbound direction (veh/h),}
\]

\[
v_{i} = \text{total volume (or through volume) of an arterial street in the segment between intersection } i \text{ and } i+1 \text{ in outbound direction (veh/h), and}
\]

\[
v_{i} = \text{total volume (or through volume) of an arterial street in the segment between intersection } i \text{ and } i+1 \text{ in inbound direction (veh/h).}
\]

Furthermore, two other important variables are defined as follows:
\( C \) is cycle length of signalized intersection \( i \) (s), and \( R_i \) is red interval in the arterial street direction at intersection \( i \) (s).

Thus, the optimal solution can be obtained by the following process:

Maximize \( B = B(O_i, O_2, \ldots, O_N, P_{S_1}, P_{S_2}, \ldots, P_{S_N}) \) (5)

subject to the conditions

\[
O_i \leq C_i \quad \text{for} \ i = 1, 2, \ldots, N
\] (6)

\[
P_{S_i} = 1, 2, 3, \text{or} 4 \quad \text{for} \ i = 1, 2, \ldots, N
\] (7)

and assuming other parameters are predetermined.

To determine the value of Eq. (1), four functions must be defined. The first function is the weight coefficient function in the outbound direction, which is expressed as:

\[
k_{j,i} = k(c_{j,i}, v_{j,i}) = \alpha_j \times \left( \frac{v_{j,i}}{c_{j,i}} \right) \beta
\] (8)

Here, \( \alpha_j \) is a coefficient whose value is greater than 0. \( \beta \) is a coefficient whose value is greater than or equal to 0.

Similarly, the weight coefficient function for the inbound direction is given in Eq. (9).

\[
k_{j,i} = k(c_{j,i}, v_{j,i}) = \alpha_j \times \left( \frac{v_{j,i}}{c_{j,i}} \right) \beta
\] (9)

and,

\[
h_{j,i} = h(O_i, P_{S_1}, GIBL_i, GIBT_i, d_{s,i}, s_{i,j}, O_{i,j}, P_{S_1} = 1, 2, 3, \text{or} 4 \quad \text{for} \ i = 1, 2, \ldots, N
\] (10)

where \( h(j, O_i, P_{S_1}, GIBT_i, GIBL_i, d_{s,i}, s_{i,j}, O_{i,j}) \) is an 0-1 function that determines whether the signal light is available for this through movement at time \( j \). “1” means vehicles can go through the intersection in the outbound direction, and “0” means vehicles cannot pass the intersection at this time. This function is determined by the offset \( O_{i,j} \), NEMA phase sequence pattern \( P_{S_1} \), effective green time of the outbound through movement \( GIBT_i \), effective green time of the inbound left turn movement \( GIBL_i \), cycle length \( C_i \), and red interval in arterial street direction \( R_i \) at the signal intersection \( i \).

This function can be defined by:

\[
f(j, O_i, P_{S_1}, GIBT_i, GIBL_i, d_{s,i}, s_{i,j}, O_{i,j}) = \begin{cases} 1, & \text{if } O_i - R_i - GIBT_i < \delta(j - O_i - R_i) \text{ or } GIBL_i \leq \delta(j - O_i - R_i) \\ & \text{and } (j - O_i - R_i) \leq GIBT_i, \text{if } P_{S_1} = 1, 3 \\ 0, & \text{otherwise, if } P_{S_1} = 1, 3 \\ \\ 1, & \text{if } O_i - R_i - GIBT_i < \delta(j - O_i - R_i) \text{ or } GIBL_i \leq \delta(j - O_i - R_i) \\ & \text{and } \delta(j - O_i - R_i) \leq GIBT_i, \text{if } P_{S_1} = 2, 4 \\ 0, & \text{otherwise, if } P_{S_1} = 2, 4 \\ \\ \\ \\ \end{cases}
\] (11)

\( f_i' (j, O_i, P_{S_1}, GIBT_i, GIBL_i, d_{s,i}, s_{i,j}, O_{i,j}) \) is the shift of \( f_i (j, O_i, P_{S_1}, GIBT_i, GIBL_i, d_{s,i}, s_{i,j}, O_{i,j}) \) can be obtained by moving \( f_i (j, O_i, P_{S_1}, GIBT_i, GIBL_i, d_{s,i}, s_{i,j}, O_{i,j}) \) with time \( t_{i,j} = d_{s,i} - s_{i,j} \), along the direction of coordination, as seen in Fig. 3. Eq. (10) means that the total bandwidth between intersection \( i \) and \( i+1 \) equals the sum of time for vehicles going through the upstream intersection \( i \) and can also pass the current intersection \( i+1 \). Fig. 3 shows that the outbound bandwidth is 5 s which is the sum of five “1” in one cycle.

Here, \( j \) and \( j' \) satisfy the following relationship:

\[
j = (j' + t_{i,j}) \mod(C_i)
\] (12)

To explain this method clearly and simply, the parameters and functions along the outbound direction are shown in Fig. 3 which describes the process of how to obtain the bandwidth 12 by Eqs. (10) to (13) in detail.

For inbound direction, the functions can be defined based on the above method. The equations are as follows:

\[
d_{j+1} = h(O_i, P_{S_1}, GIBL_i, GIBT_i, d_{s,i}, s_{i,j}, O_{i,j}, P_{S_1} = 1, 2, 3, \text{or} 4 \quad \text{for} \ i = 1, 2, \ldots, N
\] (10)

where \( f_i (j, O_i, P_{S_1}, GIBT_i, GIBL_i, d_{s,i}, s_{i,j}, O_{i,j}) \) is a 0-1 function that determines whether the signal light is available for this through movement at time \( j \). “1” means that vehicles can go through the intersection in the inbound direction, and “0” means that vehicles cannot pass through the intersection at this time. This function is determined by the offset \( O_i \), NEMA phase sequence pattern \( P_{S_1} \), effective green time of inbound through movement \( GIBT_i \), effective green time of outbound left turn movement \( GIBL_i \), the cycle length \( C_i \), and red interval in arterial street direction \( R_i \) at the signal intersection \( i \).

This function can be defined by:

\[
f_j (j, O_i, P_{S_1}, GIBL_i, GIBT_i, C_i, R_i) = \begin{cases} 1, & \text{if } (O_i - R_i - GIBT_i) \leq \delta(j - O_i - R_i) \text{ or } GIBL_i \leq \delta(j - O_i - R_i) \\ 0, & \text{otherwise, if } P_{S_1} = 1, 3 \\ 1, & \text{if } (O_i - R_i - GIBL_i) \leq \delta(j - O_i - R_i) \text{ or } GIBL_i \leq \delta(j - O_i - R_i) \\ 0, & \text{otherwise, if } P_{S_1} = 2, 4 \\ \end{cases}
\] (12)
when the weighted sum of bandwidth is the maximum amongst all the scenarios.

2.2 Network coordination model

For networks, the basic idea of how to obtain an optimal coordination plan is similar to the arterial coordination model. However, some additional parameters must be explained to describe the network model clearly. A 3 × 3 network is shown in Fig. 4. The goal of this network model is to obtain the maximum weighted sum of all 24 possible bandwidths based on given conditions and constraints. One issue that must be addressed before explaining this model is the constraint of offset in the vertical direction when the offset in the horizontal direction is changing at one signalized intersection (Fig. 5). When the offset in the horizontal direction is shifting from time A to B (one cycle) at intersection 11, the offset in vertical direction is moving from time A’ to B’ (also one cycle). This means only offsets along one arterial street for all signalized intersections in the network needs to be analyzed. Cross street offsets can be determined in the process of searching the optimal solution, which saves a large amount of computer calculation time.

The optimal solution for a coordinated traffic signal control plan in a traffic network with M horizontal arterial streets and N vertical arterial streets can be obtained through the following process:

Maximize $B = B(O_{1,1}, O_{1,2}, \ldots, O_{i,j}, O_{i,2}, \ldots, O_{i,N}, \ldots, O_{N,1}, O_{N,2}, \ldots, O_{N,2}, \ldots)$, $O_{1,1}, O_{1,2}, \ldots, O_{M,2}, \ldots, O_{M,1}, O_{M,2}, \ldots, O_{M,2}, \ldots, O_{N,1}, O_{N,2}, \ldots, O_{N,2}, \ldots, O_{N,1}, O_{N,2}, \ldots, O_{N,2}, \ldots, O_{N,1}, O_{N,2}, \ldots, O_{N,2}, \ldots$.
\[ PS_{i,j,H} \] \tag{17}

Subject to the constraints
\[ 0 \leq O_{i,j,H} \leq C_{ij} \quad \text{for } i=1,2,\ldots, N; \quad j=1,2,\ldots, M; \quad H: \text{horizontal arterial street} \] in network in Fig. 5.
\[ PS_{i,j,V} = 1, 2, 3 \text{ or } 4 \quad \text{for } i=1,2,\ldots, M; \quad j=1,2,\ldots, N; \quad H: \text{horizontal arterial street} \] in network in Fig. 5.
\[ PS_{i,j,V} = 1, 2, 3 \text{ or } 4 \quad \text{for } i=1,2,\ldots, M; \quad j=1,2,\ldots, N; \quad V: \text{vertical arterial street} \] in network in Fig. 5.

Assume all other parameters are predetermined in this model. A comprehensive search is also used for maximizing the objective function in here.

\[ O'_{i,j,H}, \quad PS'_{i,j,H} \text{ and } PS'_{i,j,V} \text{ must be determined to} \]
produce the maximum weighted sum of bandwidth of traffic network. Eq. (17) can be expanded as follows:

\[
B = \sum_{i=1}^{N} \sum_{j=1}^{M} (k_{i,j+1,H} \times b_{i,j+1,h} + k_{i,j+1,V} \times b_{i,j+1,v}) + \sum_{j=1}^{N} \sum_{i=1}^{M} (k_{i+1,j,V} \times b_{i+1,j,v} + k_{i+1,j,H} \times b_{i+1,j,h}) \tag{18}
\]

where,
\[ k_{i,j+1,H} = \text{weight coefficient of link between intersection } j \text{ and } j+1 \text{ in outbound direction along the } i^{th} \text{ horizontal arterial street}, \]
\[ k_{i,j+1,V} = \text{weight coefficient of link between intersection } j \text{ and } j+1 \text{ in inbound direction along the } i^{th} \text{ horizontal arterial street}, \]
\[ k_{i+1,j,V} = \text{weight coefficient of link between intersection } i \text{ and } i+1 \text{ in outbound direction along the } j^{th} \text{ vertical arterial street}, \]
\[ k_{i+1,j,H} = \text{weight coefficient of link between intersection } i \text{ and } i+1 \text{ in inbound direction along the } j^{th} \text{ vertical arterial street}, \]
\[ b_{i,j+1,H} = \text{outbound bandwidth between intersection } j \text{ and } j+1 \text{ along the } i^{th} \text{ horizontal arterial street (s)}, \]
\[ b_{i,j+1,V} = \text{inbound bandwidth between intersection } j \text{ and } j+1 \text{ along the } i^{th} \text{ horizontal arterial street (s)}, \]
\[ b_{i+1,j,V} = \text{outbound bandwidth between intersection } i \text{ and } i+1 \text{ along the } j^{th} \text{ vertical arterial street (s)}, \]
\[ b_{i+1,j,H} = \text{inbound bandwidth between intersection } i+1 \text{ and } j \text{ long the } j^{th} \text{ vertical arterial street (s)}. \]

All the weight coefficients and bandwidths in Eq. (18) can be obtained by the methods used in the arterial coordination model discussed previously. The only matter that must be addressed is how to determine the offset in vertical direction given the offset in horizontal direction for each signalized intersection. Using intersection \( ij \) located at the crossing of \( i^{th} \) horizontal arterial and \( j^{th} \) vertical arterial in the network) as an example, the offset in the vertical direction at this intersection given a horizontal direction offset can be obtained by the following equation:

\[ O_{i,j} = \left[ O_{i,j,H} + (GOBL_{i,j,H} + GIBL_{i,j,H}) \right] \mod C_{i,j} \tag{19} \]

where,
\[ O_{i,j,H}=\text{the offset in vertical direction at intersection } ij, \]
\[ O_{i,j,H}=\text{the offset in horizontal direction at intersection } ij, \]
\[ GIBL_{i,j,H}=\text{the effective green time of the through movement in outbound direction along horizontal direction at intersection } ij, \]
\[ GIBL_{i,j,H}=\text{the effective green time of the left movement in inbound direction along horizontal direction at intersection } ij, \]
\[ C_{i,j}=\text{the cycle length of intersection } ij. \]

3 Model applications

Both the arterial and network models are implemented by Visual C++ 2008, a programming environment used to create computer applications for the Microsoft Windows family of operating systems. Two examples are presented to illustrate how to use the models to derive the optimal solution. The first example applies the arterial coordination model to an arterial consisting of four intersections. The main outputs of this model include the offsets and NEMA phase sequence patterns for each intersection to achieve the highest total sum of weighted bandwidth in both inbound and outbound directions.

All the input parameters for the example case are shown in Fig. 6, and the results are illustrated in Fig. 7.

![Fig. 6 An example of coordination along the arterial street with four signalized intersections](image-url)
The sum of weighted bandwidth is 256.5 s, and the sum of bandwidth for both directions is 287 s. The bandwidths of each street segment in the arterial are shown in Fig. 7. The best coordinated signal control solution for this arterial street can be obtained when the offset of intersection 1 is 0 s and the NEMA phase sequence pattern is 2; intersection 2 has an offset of 46 s and NEMA phase sequence pattern is 3; the offset of intersection 3 is 0 s with NEMA phase sequence pattern 1; intersection 4 has an offset of 134 s and NEMA phase sequence pattern 3. Incorporating the given (input) parameters, these settings used at these four intersections can produce an optimal traffic signal coordination plan.

The second example is an application of the network coordination model on a simple network composed of two east-west and two north-south streets. The input information for the model includes cycle lengths, effective green times of each phase for every intersection, travel times, and weights of bandwidth in each direction for every segment. The offsets and NEMA phase sequence pattern for each intersection to obtain the largest sum of weighted bandwidth are provided through this model. All the input parameters of the example are shown in Fig. 8, and the results are illustrated in Fig. 9. The sum of weighted bandwidth is 90.8 s, and the sum of bandwidth in both directions is 100 s. The bandwidth of each
street segment in the arterial is shown in Fig. 9. The best coordinated signal control plan for this arterial network occurs when the offset of intersection 11 in the east-west direction is 0 s and NEMA phase sequence pattern in the east-west direction is 1, and 4 in the north-south direction; intersection 12 has an offset of 30 s in the east-west direction and NEMA phase sequence pattern of 2 for both directions; an offset at intersection 21 in east-west direction is 0 s with NEMA phase sequence of 2 for both directions, and intersection 22 has an offset in the east-west direction of 4 s and NEMA phase sequence pattern of 1 for both the east-west and north-south directions. Given the input parameters, the above results represent the best-coordinated signal control plan for this network.

Fig. 9 Results from the network coordination model for a 2×2 network

4 Conclusions

This paper applies two main models (arterial coordination model and network coordination model) to obtain best signal timing strategies for coordinating signals on arterials and street networks. The arterial coordination model is used for determining the offsets and NEMA phase sequence patterns at intersections to achieve the maximum weighted sum of bandwidth in both directions. The network coordination model expands upon the arterial model to obtain the maximum weighted sum of bandwidths for a network. The problems solved by the arterial coordination model are, in essence, special cases that can be solved by the network coordination model. The two examples illustrated in this paper demonstrate the ability and feasibility of applying these two models in practice.

The basic idea of these two models is significantly different from those documented in previous literatures. The concept used in these models is simple to follow compared to the MILP developed by Little et al. In fact, the best solutions of these coordination issues are not unique. Then, the significance of this research is that any signalized networks of various configuration can be solved using the proposed models. These different network configurations may include one-way streets, diamond intersections, and T-intersections. There are not so many “loop” constraints in this new network coordination model compared to the MILP method. In general, this new model can solve any size of network and various types of signal intersection in urban areas regardless of time consumed in theory. The only challenge of the proposed models is the extensive computation time that increases greatly with the size of a traffic network. In the first example provided above, the model spent approximately 30 s when there was only one selection of phase sequence type for every intersection. The model spent almost 2 min when three of these four intersections had only one selection of phase sequence type, and the other one had four options of phase sequence type. The model needed nearly 2 h to provide the results when four options of phase sequence type for each intersection are selected. The network coordination model application example presented in this paper spent more than 72 h in total to provide the results. However, this is not a particular concern due to the increased computer power. Nevertheless, efficient programming of the computer code is always desired for achieving higher computing efficiency. Because the scope of this study is limited to determining only the offset and phasing sequence, additional research is needed for selecting the optimal cycle length, phase splits, and the weighted bandwidth coefficients.

References


