PLATOON-BASED ARTERIAL SIGNAL COORDINATION
WITH UNEVEN DOUBLE CYCLING

A Ph.D. Dissertation Proposal

By

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INTRODUCTION

As traffic volume has increased over the past two decades, the total hours of national urban traffic delay has almost doubled. Traffic agencies have to use long cycle lengths (often over 150 seconds) during peak hours to provide adequate two-way arterial progression between large intersections and to alleviate congestion at the critical intersections. However, conventional arterial coordination using long cycle lengths can cause excessive delay for drivers on the cross streets of minor intersections. With the introduction of 16-phase controllers, one tool to address this issue is the use of an “uneven double cycle” (UDC) control scheme, where the key phases in a cycle are unevenly repeated twice during the background cycle. Figure 1 shows an example of the phase sequence and splits using an UDC scheme.

![Figure 1. Phase Sequence and Splits Using an Uneven Double Cycle](image)

The UDC scheme shown above services all through movements twice (typically unequally) and typically services the major street left-turn once per background cycle at the minor intersections. The scheme is able to reduce delay on cross streets without impeding the passage of the green band in either direction on the major street. At present, the UDC timing scheme is developed manually and may not be optimal, and few studies have addressed its development procedure or the method of optimizing coordination. This research will develop a UDC-enabled arterial signal coordination optimization method that incorporates platoon prediction models using offline traffic volume data.

Problem Statement

Implementing the UDC scheme in arterial signal coordination presents several challenges for the conventional offline coordination optimization process. Basically, the UDC scheme adds several new variables to conventional coordination optimization. The scheme needs to choose between
single cycling and double cycling for each intersection along the arterial. Each intersection that chooses uneven double cycling also needs to determine the green splits of twice-served phases and the sequence of arterial left-turn phases. Moreover, the UDC scheme needs to account for varying traffic demand in the offline optimization process. The scheme actually makes use of the slack time of reduced arterial traffic demand at the minor intersections to service minor street phases; therefore it becomes a challenge to depict demand variation based on narrowly (peak 15 minutes) defined data to optimize coordinated signal timing. Furthermore, realizing the benefit of the UDC scheme requires balance between conflicting optimization objectives, which conventional coordination programs often do not consider. Since splitting a long cycle into two sub-cycles to reduce the delay on minor streets potentially reduces the maximum achievable green bandwidth, maximized bandwidth and minimized total delay are two conflicting issues. A potential solution to these issues is to develop an offline optimization program that properly defines variables and objectives and uses the platoon information as input predicted from limited data. Such a program will facilitate the practice of the UDC scheme and make better use of current resources.

**Research Objectives**

The goal of the research is to develop an offline arterial signal coordination optimization model that utilizes the uneven double cycling scheme based on offline data. To this end, the research entails the following objectives:

- predict platoon characteristics based on offline data and identify platoon-based delay function for arterial signal coordination
- develop a platoon-based optimization model that can properly provide double cycling to reduce delay at minor intersections without compromising good progression
- evaluate the performance of the proposed model and provide guidelines for various field conditions where implementing the UDC scheme is beneficial

**Background**

At present, the UDC scheme is used on a limited base, even though there are advanced signal controllers that are available to implement UDC practices. Because the UDC scheme utilizes more than eight phases, traditional 8-phase controllers are not capable of realizing such control
scheme, and 16-phase controllers (or controllers with more phase capability) are required. For the UDC example shown in Figure 1, the two services of through movements must be driven as an overlap made up of two separate phases, Ø4 and Ø14, and the second phase, Ø14, is assigned to the same load switch channel normally assigned to the first phase, Ø4. This allows two different split times assigned to the same through movements at minor intersections, so that two shorter cycles exist under a long background cycle required by the major intersections \( J \). The City of Garland, Texas has implemented the UDC control scheme and has reported the reduced maximum wait times at most of minor intersections and good citizen acceptance \( (2) \). However, few studies have addressed the signal timing procedure or the coordination optimization method utilizing the UDC scheme, and few signal coordination optimization software are capable of incorporating the scheme; therefore traffic agencies have to manually achieve the optimum signal plans of the UDC scheme based on some signal optimization software, e.g., Synchro. They first design the ring-and-barrier diagrams for intersections with UDC and determine the appropriate split times using V/C ratios; then they iteratively adjust the phase sequences and offsets for all intersections, the sub-green splits of through phases, and the left-turn phase association with the through phases for double-cycled intersections \( (2) \). Such a design process is cumbersome and does not necessarily yield the optimal timing plan. Modeling UDC-enable arterial coordination and developing guidelines for UDC implementation could potentially save time and cost of the signal timing design process.

**Platoon Modeling and Platoon-Based Signal Design**

The Highway Capacity Manual defines a platoon as a group of vehicles traveling together because of signal control, geometrics, or other factors \( (3) \). When successive vehicle discharge headways at an upstream intersection are smaller than the predefined critical headway, these vehicles form a multivehicle platoon. Individual vehicles not in a platoon with other vehicles belong to single-vehicle platoons. Description of the platoon could use platoon size (number of vehicles in a platoon), platoon speed (average speed of vehicles in a platoon), platoon headway (average vehicle headway within a platoon), and inter-platoon headway (headways between the last vehicle of the leading platoon and the first vehicle of the following platoon) \( (4) \). The number of arriving platoons, the inter-platoon headways, and the platoon size of each platoon have been reported to follow the Poisson distribution, the lognormal distribution, and the negative
exponential distribution respectively; and both the platoon headway and platoon speed follow the normal distribution \( (5) \).

Previous studies on platoon modeling are mainly for dispersion and have branched into three major areas: the kinematic wave model \( (6) \) relies on accurate representation of the flow-density relationship \( (7) \); the diffusion theory \( (8) \) assumes that individual speeds are constant and normally distributed and that overtaking is free; the recursive model \( (9) \) uses field data to derive an empirical method for predicting platoon behavior. Recent studies have also applied the Markov Chain theory to model the platoon dispersion by predicting changes in arrival flow \( (10) \) or the speed \( (11, 12) \). Platoon interaction has not received enough research attention besides a few efforts that use the shock wave theory to model platoon compression \( (13) \) and platoon merging \( (10) \).

Existing offline arterial coordination programming does not usually consider platoon evolution in the formulation despite some efforts made in using platoon dispersion models or detected platoon data. There are studies incorporating the recursive platoon dispersion into the network coordination programming to minimize the total delay \( (14) \) or into the MAXBAND programming by revising the expression of travel time \( (15) \). Another two studies developed signal timing design methods for individual intersections \( (4) \) and adaptive arterial control \( (16) \) using directly detected platoon data. These studies have reported that the platoon-based signal timing methods outperform conventional flow-based methods.

**Delay Estimation Method**

Vehicles passing intersection often experience delay because of stopping during red phases or reducing speed when moving through queues. Numerous studies have applied queuing theories to estimate intersection delay, which typically include deterministic analysis, stochastic analysis, and shock wave analysis. The deterministic modeling assumes uniform traffic arrival patterns, whereas the stochastic model assumes that the arrivals follow certain probability distribution. Stochastic queuing analyses can be further categorized into steady-state and time-dependent stochastic models depending on whether the queue distribution changes over time. Most of the deterministic and stochastic delay models also assume that vehicles queue vertically and
accelerate and decelerate instantaneously, which indicates the ignorance of platoon interaction. The shock wave delay models utilize the macroscopic traffic flow model to estimate the queuing process in terms of wave propagation, which consider that the vehicles queue horizontally and still accelerate and decelerate instantaneously.

In the steady-state stochastic delay modeling, the most fundamental work is the Webster’s model (17), which consists of the uniform delay, the incremental delay because of random arrivals, and the empirical correction factor according simulation results. The Webster model and some similar models (18,19,20) assume that traffic arrivals follow stationary Poisson distribution and thus are not applicable for coordinated system. The time-dependent stochastic modeling is first introduced to provide a general model that connects the deterministic and steady-state stochastic models (21,22). Several of the time-dependent models formulate the queue evolution as a one-step Markov process cycle by cycle (23,24,25) and within a cycle (26).

Only a few queuing models consider the platoon arrivals for uniform delay (27) and overflow delay (28). In the uniform delay modeling, platoons are assumed to arrive at the downstream intersection in two average flow rates (one within the green band, and another outside of it) (27). In the overflow delay modeling, the steady-state overflow delay equation is adopted for both random and platoon arrivals (28). The time-dependent stochastic modeling approach has rarely been considered for platoon-based delay modeling.

**Conventional Arterial Signal Coordination Methods**

Conventional arterial signal optimization programs fall into three categories: bandwidth-based, delay/stop-based models, and multiobjective models. The bandwidth-based programs, e.g., PASSER II, generate the cycle lengths, offsets, and phase sequences to maximize the sum of directional green bands for progression (29). Research efforts have been made to improve the bandwidth-based programs through generating variable bandwidth (30), circular phasing (31), or optimal green splits (32). The delay/stop-based programs, e.g., TRANSYT, minimize the linear combination of delay and stops by optimizing cycle length, green split, and offset. The latest version of the TRASYT-7F (release 11) can also optimize phase sequences. The bandwidth-based programs oversimplify traffic flow condition in the modeling and may result in
unnecessary delay for cross-street traffic, whereas the delay/stop-based programs often do not produce good progression bands. As a consequence, research efforts have been made in combining the merits of both types of methods to provide good progression and minimal delay (33,34,35). However, none of these programs are capable of producing conditional services such as an uneven double cycling.

**RESEARCH TASKS**

This research will develop an arterial signal coordination method that enables the use of the uneven double cycling scheme and that incorporates the platoon-based delay prediction modeling. The research will begin with reviews of conventional methods in platoon modeling, delay estimation, arterial signal coordination, and optimization solutions. One of the main research activities will be developing a platoon-based delay model using the Markov Chain theory to provide analytical and approximate equations for delay estimation. Another focus of the research will be formulating the arterial signal coordination problem in two ways: maximizing bandwidth while minimizing total delay, and only minimizing the total delay. The researcher will apply the discrete event simulation approach in modeling platoon evolution and in optimizing arterial signal timing plans. The resulting models from the two major research activities will be then calibrated and evaluated using simulation and/or field data. Finally, the researcher will compare the proposed model with conventional arterial coordination methods and conduct a case study to illustrate its application.

**Task 1. Literature Review**

The initial step in this study is a thorough literature review on the subject to understand previous work and topics associated with the research. This background information will aid the researcher throughout the entire process. Specific areas of interest for the literature review are:

- background on double cycling and conventional arterial signal coordination design
- previous studies on platoon prediction models and delay estimation methods
- previous studies which modeled arterial traffic characteristics as a Markov process
- previous studies on multiobjective optimization and solution algorithms
Task 2. Platoon-Based Delay Function Development

The purpose of Task 2 is to identify proper delay functions that utilize the predicted platoon as the input information. The first focus of Task 2 is to develop a generalized platoon prediction model based on offline data and to generate the arrival platoon profile for each intersection using the Markov Chain (M.C.) theory. Existing platoon modeling often emphasizes platoon dispersion in a single lane, while arterial platoon pattern changes have appeared as more than just platoon pattern changes exist among vehicles in different lanes; compression happens to platoons entering the arterial link during red and green times (13); interaction occurs when a following platoon catching a leading platoon either stopped or slowed down by a downstream signal.

Platoon prediction modeling in this research will feature the following characteristics to tackle the above issues:

- instead of dealing with single lane traffic, modeling of platoon formation and splitting considers vehicles across all lanes
- providing platoon passage time at the downstream intersection to cover both dispersion and compression phenomena
- considering queue length at the downstream intersection in modeling platoon arrivals to account for platoon interaction

Markov Chain Theory in Platoon Modeling

This research will rely on headway prediction to identify platoon patterns. Platoon dispersion and compression reflect in the changes of individual headways of a platoon, and platoon splitting and merging depend on the relationship between individual headways and the predetermined critical headway. As vehicles discharging in platoons from an upstream intersection proceed, the initial individual headways in each platoon and between platoons increase or decrease to cause platoon dispersion or compression. A primary platoon may split into two or more secondary platoons at a downstream intersection when one or more vehicle headways in the original platoon become greater than the critical headway. Two or more platoons may also merge into one platoon if the inter-platoon headways become smaller than the critical headway. Through predicting headway changes along the arterial links, platoon patterns and the corresponding platoon passage time at the downstream intersections are predictable.
The researcher will be applying the Markov Chain theory for arterial headway prediction in platoon modeling. A Markov Chain is a stochastic process that assumes the conditional distribution of any future state $X_{n+1}$ given the past states $X_0, X_1, \ldots X_n$, and the present state $X_n$, is independent of the past states and depends only on the present state:

$$P(X_{n+1} = j | X_n = i, X_{n-1} = i_{n-1}, \ldots X_0 = i_0) = P(X_{n+1} = j | X_n = i) = P_{ij}$$

Where $P_{ij}$ is the probability of state $i$ transiting to state $j$. The matrix consisting of elements probability $p_{ij}$ is the one-step transition probability matrix, the key component of the Markov Chain. Given the initial state and the transition matrix, the future states can be determined as (36):

$$P(X_n = i) = \sum_{j=0}^{\infty} P(X_n = j | X_0 = i)P(X_0 = i) = \sum_{j=0}^{\infty} P_{ij}^n P(X_0 = i)$$

The Markov Chain theory has been widely used in traffic modeling, such as arrival flow prediction (10), speed prediction (11,12), delay estimation (23-26), travel time prediction (37), and freeway spacing and headway prediction (38). The Markov Chain modeling of arterial headways is complicated by signal timing and turning movements, yet is still feasible.

For the purpose of predicting arterial platoon pattern evolution, prediction of each headway in the same platoon position needs to define two Markov Chain processes: the arrival M.C. and the departure M.C. The arrival M.C. starts at the time the platoon passing the link entrance (entrance of the receiving through lanes on the major street at the upstream intersection) and ends at the time the platoon passing some distance upstream of the link exit (stop bar of the downstream intersection). The departure M.C. starts at the end point of the arrival M.C. and ends at the next link entrance as the future state. The researcher defines the connecting point of both Markov Chains as the critical platoon location. Figure 2 shows the arterial locations of the two Markov Chains.

![Figure 2. Locations of Arrival Markov Chain and Departure Markov Chain](image-url)
Noting that the transition probability matrix of headway states needs to be stationary or homogeneous, it is important to properly identify the critical platoon location that defines the arrival and departure Markov Chain segments. Each Markov Chain segment should have a collection of headway states representing a relatively stable traffic condition considering flow levels at the upstream intersection, queue length at the downstream intersection, and signal phases. The researcher expects that the critical location reflects the interface where the headway distribution at each platoon position starts to become from stable to instable under certain traffic scenario or the shapes of the headway distributions appear significant changes. Analyzing headway distributions under various traffic scenarios at different locations along the link can determine the transition matrix of each Markov Chain and the corresponding headway evolution.

The researcher will further derive the analytical expressions to describe platoon arrivals and departures. First, the elapsed time (or travel time) of each pair of vehicles in the arrival M.C. will be a probabilistic function of headway, speed, and travel distance; and the elapsed time of each pair of vehicles in the departure M.C. will be a function of confronted signal phase, turning probability, headway, speed, and travel distance. These functions will be used to estimate platoon arrival times at the critical location and link entrance. Second, description of platoons will rely on predicted headway distributions. The comparison between individual headways and the predefined critical headway determines the platoon size; the sum of headways in a platoon determines the platoon’s passage time at the stop bar during red and green phases separately. Platoon speed estimation can either rely on the known stationary platoon speed distribution (4) or also resort to Markov Chain estimation (11, 12). During the peak hour, the traffic input on the major street approaches of the starting intersections and cross-street approaches of all intersections along the arterial are assumed to have known stationary distributions. Then platoon evolution along the arterial links is predictable.

Platoon-Based Delay Estimation
Another focus of Task 2 is to estimate delay based on the stochastic platoon patterns. Each platoon arrives at the intersection at different time points and has a passage time with certain probability. The platoon may clear the intersection, or a proportion or all of its vehicles may stop

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due to the red signal or the stopped leading platoon, depending on the arrival time with respect to
the start of green (or red) phase. With signal timing parameters and the probabilistic platoon
information available, the researcher will derive the probability function that part or all vehicles
in a platoon are stopped at an intersection and identify the expectation and variances of the
incurred delay for all major street approaches during green and red phases within a signal cycle.
For delay on the minor street approaches, conventional volume-based delay estimation methods
will be used.

Considering the characteristics of the UDC scheme, estimation of the total intersection delay
may necessitate assigning different weights to different delays. The platoon interruption incurred
delay may need a higher weight than that of stopping a full platoon incurred delay on major
approaches; excessive vehicle delay on minor approaches where lane blockage and/or spillback
may happen due to long queues in short turning bays and/or short links may need a weight that is
higher than delay on other minor approaches and even on the major approaches. These weights
could be arbitrarily assigned or be set as variables and determined in the optimization process.

Task 3. UDC-Enabled Arterial Coordination Optimization
This research task is to formulate the UDC-enabled arterial signal coordination problem to
provide signal timing plans that satisfy different objectives of signal control. This part of
research consists of the following subtasks:

- enable the UDC control scheme in the original MAXBAND formulation
- incorporate platoon information and platoon-based delay estimation in the formulation of
  the optimization problem
- solve the optimization problem efficiently

Formulation of UDC-Enabled Arterial Coordination Problem
The first focus of Task 3 is to modify the original MAXBAND formulation to incorporate the
UDC scheme and the predicted platoon information. According to the relative location of an
UDC intersection and the green band choice, there exist nine possible combinations of
intersections in the UDC control scheme. Table 1 and Figure 3 provide descriptions and examples of respective scenarios.

Table 1. Combinations of intersections in UDC-enabled arterial two-way progression

<table>
<thead>
<tr>
<th>Notation</th>
<th>Intersection i</th>
<th>Intersection i+1</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_S</td>
<td>Single Cycling (S)</td>
<td>Single Cycling (S)</td>
<td>Single-cycled i &amp; i+1</td>
</tr>
<tr>
<td>D1_S</td>
<td>Double Cycling I (D1)</td>
<td>Single Cycling (S)</td>
<td>Green bands pass the same green phase at double-cycled i, single-cycled i+1</td>
</tr>
<tr>
<td>D2_S</td>
<td>Double Cycling II (D2)</td>
<td>Single Cycling (S)</td>
<td>Green bands alternately pass different green phases at double-cycled i, single-cycled i+1,</td>
</tr>
<tr>
<td>S_D1</td>
<td>Single Cycling (S)</td>
<td>Double Cycling I (D1)</td>
<td>Single-cycled i, green bands pass the same green phase at double-cycled i+1</td>
</tr>
<tr>
<td>D1_D1</td>
<td>Double Cycling I (D1)</td>
<td>Double Cycling I (D1)</td>
<td>Green bands pass the same green phase at double-cycled i &amp; i+1</td>
</tr>
<tr>
<td>D2_D1</td>
<td>Double Cycling II (D2)</td>
<td>Double Cycling I (D1)</td>
<td>Green bands alternately pass different green phases at double-cycled i, green bands pass the same green phase at double-cycled i+1</td>
</tr>
<tr>
<td>S_D2</td>
<td>Single Cycling (S)</td>
<td>Double Cycling II (D2)</td>
<td>Green bands alternately pass different green phases at double-cycled i, single-cycled i+1</td>
</tr>
<tr>
<td>D1_D2</td>
<td>Double Cycling I (D1)</td>
<td>Double Cycling II (D2)</td>
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<td>Green bands alternately pass different green phases at double-cycled i &amp; i+1</td>
</tr>
</tbody>
</table>

Figure 3. Progression Scenarios in UDC-enabled Arterial Two-way Coordination
To formulate these scenarios, the researcher will introduce four sets of important variables: the nominal reds, the sub-phase ratios, the green band passage selection flag, and the left-turn allocation flags. The nominal red variable equals the background cycle length minus the sub-green time chosen for green band passage (Figure 4). Introducing the nominal reds can accommodate the inbound and outbound red center offset at a double-cycled intersection, and the basic loop function of the original bandwidth geometry still holds for all the above scenarios.

**Figure 4. Bandwidth Geometry at Single-Cycled and Double-Cycled Intersections**

The sub-phase ratio is the ratio between the first sub-green (sub-red) time and the total green (red) time of a double-serviced movement at a double-cycled intersection. The green band passage selection flag is a binary variable for choosing one of the sub-green phases as the green band. The left-turn allocation flag is a binary variable for associating the left turn phase to one of the sub-green through phases. With the three variables, the green splits and the phasing sequence of a double-cycled intersection can be calculated, and thus the nominal red and the corresponding inbound and outbound red center offset are also determined.

Full mathematical formulation of the UDC-enabled coordination problem will utilize the predicted platoon information and consider two sets of optimization objectives. Instead of using speed and travel time of individual vehicles, the travel time constraint incorporates the platoon speed and platoon travel time to account for varying traffic flow. Intersection delay comprises of platoon delay on the major street approaches and vehicular delay on the minor cross street approaches. To achieve both maximal bandwidth and minimal total delay, a bi-level optimization structure can be utilized with the minimized total delay being one of the constraints. An
alternative is to sum the weighted bandwidth and delay as a single objective function and to find the optimal solution to the function. Another optimization objective of interest is to only minimize the sum of weighted arterial delay and cross-street delay. Inclusion of the minimal-delay-only analysis is attempted to examine whether the delay-based objective is sufficient in the arterial signal optimization given the consideration of platoon patterns in delay estimation.

**Solution to the UDC-Enabled Coordination Optimization Problem**

The researcher will apply the discrete event simulation approach in an attempt to integrate the prediction of platoons and delay and the optimization of signal timing plans into a single program. The platoon prediction module simulates the platoon evolution process along the arterial links given an initial signal timing plan generated from a conventional timing model, e.g., the original MAXBAND program. The output of this module is the platoon arrival profile for each intersection with respect to time. The delay module provides delay estimation given the platoon and signal timing information. The output of this module is the expectation of delay during each of the green and red phases under steady state. The signal timing module will then utilize the delay estimation to update the signal timing plan that enables the UDC scheme. This is an iterative process until certain termination criteria are met.

Proper algorithms will be selected to solve the optimization problem according to the linearity and convexity of the final models. Usually, modeling with assumptions that are less close to the reality often yields formulas of linear combination of variables in the mixed integer linear programming (MILP). Existing studies have used the standard or restricted branch-and-bound algorithm for the MILP problem. The basic idea of the branch-and-bound algorithm is to partition the set of all feasible solutions into smaller subsets and to calculate an upper (lower) bound of the subset on the objective function of the best solution therein. The computational efficiency of the process depends on the methods of partitioning and calculating of the bounds.

When the constraints and objective functions take into account of delay derivatives the modeling often becomes nonlinear and sometimes non-convex. Nonlinear programming problems often use heuristic approaches such as the genetic algorithm or the Frank-Wolfe algorithm. The genetic algorithm is a search heuristic that mimics the process of natural
evolution. It creates a population of genomes then applies crossover and/or mutation to the individuals in the population to generate new individuals. It uses various selection criteria so that it picks the best individuals for mating (and subsequent crossover). The objective function determines how good each individual is. The Frank-Wolfe algorithm is an iterative method for nonlinear programming. It first finds a feasible solution to the linear constraints using the reduced gradient method. Then it searches for a direction based on the last two trail solutions for the next iteration to get an improved solution. However, in case of a non-convex problem, the genetic algorithm and the Frank-Wolfe algorithm may stop at local optima, while global optimum that is also practical still exists. As such, combination of the heuristic approaches can be used to find better solutions. The researcher will compare different algorithms and identify proper ones to solve the optimization problems efficiently.

**Task 4. Data Collection**

The researcher will use actual field data and simulation data to calibrate and evaluate the constructed models. Field data will come from two sources: the arterial dataset from the Next-Generation Simulation (NGSIM) Community \(^{(39)}\) and the traffic volume dataset and signal timing dataset from the City of Richardson. Simulation data will be generated by transportation simulation software and numerical simulation methods.

The NGSIM online database contains two 30-minute datasets representing peak hour traffic flows on an arterial in Los Angeles, California and non-peak hour traffic flows on an arterial in Atlanta, Georgia. The datasets consist of detailed vehicle trajectory data, wide-area detector data and supporting data needed for behavioral algorithm research. Specifically, the trajectory data provide each vehicle’s coordination, velocity, acceleration, space headway, time headway, preceding and following vehicles, and origin and destination zones at each instantaneous time point. The researcher will extract headway and velocity data for the platoon modeling analysis.

The City of Richardson has implemented in their street network the UDC-enabled signal timing plans that are achieved through the manual process using the Synchro software. The street network contains fifteen coordinated arterials. The city provides five fixed timing plans for each intersection for five different periods of time on a regular day: the 160-second cycle AM and PM
peak hour plans and other three non-peak hour (off AM peak hour, midday hour, and pre-PM hour) plans having cycle lengths varying from 100 to 120 seconds. Only the peak hour signal timing plans provide the double cycling scheme at certain intersections. With the provided volume count data and the geometry information of the arterial intersections, the researcher will select actual arterial streets for case studies of the UDC-enabled coordination modeling.

The researcher will also rely upon existing transportation simulation software such as VISSIM and Synchro to facilitate model analysis and evaluation. In case of lacking sufficient field data for various scenario analyses, simulation packages like VISSIM can model ideal traffic and geometry conditions to generate headway, speed, and travel time data for the Markov Chain platoon modeling. When conducting case studies, the Synchro package can provide signal plans achieved through the manual process to compare with that optimized by the model proposed in the research for performance evaluation.

The researcher will be using the MATLAB mathematical computing package for the numerical simulation throughout the research. The MATLAB package can generate random variable data of headway and speed according to their known distributions for constructing the transition matrices and simulate sequences of random variables for the Markov Chain processes in platoon modeling. The researcher will also use the MATLAB package to conduct the discrete time simulation for all three modules for model analysis and test.

**Task 5. Modeling Performance Evaluation**

In accessing the performance of the platoon-based coordination model that enables the UDC control scheme, Task 5 will be focusing upon several aspects. First the platoon-based delay estimation model will be compared with traditional estimation methods under various traffic and control conditions to make sure model consistency and to see how provision of platoon information will change the delay estimation. Then various traffic and geometry scenarios will be simulated to evaluate the UDC-enabled coordination model in an attempt to provide preliminary guidelines for field application. Furthermore, the researcher will compare the proposed coordination model with conventional timing methods that do not involve the platoon modeling or the UDC capability to see how is the operation performance of the proposed model.
Finally, the researcher will also conduct case studies using field traffic count data to illustrate the application and performance of the proposed model.

POTENTIAL BENEFIT OF STUDY

The potential benefits of this study include the following aspects:

- improving existing bandwidth-based arterial signal timing design methods by incorporating the platoon prediction models
- automating the design process of arterial signal timing design to enable the uneven double cycling scheme
- providing preliminary guidelines for implementing the uneven double cycling scheme to reduce cross-street delay in the presence of long signal cycle length
- facilitating the realization of complicated signal control scheme that currently advanced but underutilized signal controllers are capable of

SCHEDULE OF ACTIVITIES

The following table presents a schedule of activities for this research.

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