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Proposed quick method for applying dynamic lane assignment at signalized intersections☆

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ABSTRACT

Almost all researches about dynamic lane assignment were conducted to evaluate the effectiveness of applying this technique at signalized intersections. However, little attention was given to the method of identifying quickly the optimum lane group. This research suggests a quick method to find the optimum lane group for 3-lane and 4-lane approaches at junctions where each approach has green by itself in turn using the percentage of turning movements. MATLAB environment was used to build an optimization model to find the optimal lane groups at all intersection approaches for hypothetical massive traffic demand combinations using an objective function of minimizing intersection delay. This finding represents a plausible quick method to predict the optimum lane group in the field instantaneously using the percentage of turning movements at the approach without conducting massive calculations.

1. Introduction

A considerable variability in traffic demand is expected at most signalized intersections in urban areas [1]. Most of such intersections nowadays are prone to the phenomenon of tide traffic where different traffic movements at each approach (left, through and right) are fluctuating significantly with time. This phenomenon has a significant role in degrading intersection performance and results in congestion along with excessive emissions of harmful gases. Due to the fluctuation in the relative turning movement demand at the same approach, the traditional signal optimization methods such as Webster method [2] which assumes a fixed lane configuration may result in long signal cycle duration to serve the highest turning movement demand at a given period. Allocating more lanes to serve the highest turning movement demand and then, applying the Webster method to determine the optimum cycle length will improve the intersection performance significantly. Similarly, other periods can be better served if the existing lanes are allocated dynamically based on the turning movement demand. This concept is referred to Dynamic Lane Assignment DLA. The concept of Dynamic Lane Assignment DLA has been introduced by many researchers to mitigate such operation problems. Dynamic lane assignment is a technique that allows dynamic changing of lane utilization in response to the changes in the turning movement percentages at each approach. Variable Message Signs (VMS), is one of the widely used intelligent transportation systems (ITS) in urban areas, can significantly support the implementation of DLA by providing drivers with real-time information on the existing lane group configuration while approaching signalized intersections. However, the location and timing of the displayed information on lane group configuration need to be carefully studied.

This research looks for a quick method to find the optimum lane group for 3-lane and 4-lane approaches at junctions where each approach has green by itself in turn using the percentage of turning movements. Matlab environment was used to build an optimization model to find the optimal lane groups at intersection approaches for hypothetical massive traffic demand combinations. Consequently, a relationship between optimum lane groups and turning movements was identified which, hopefully, will encourage a practical application of the DLA principle.

2. Literature review

Few studies in the literature investigated the effectiveness of applying Dynamic lane assignment technique at signalized intersections serving fluctuating demand.

Wong & Wong [3] developed a binary-mix-integer linear optimization model to integrate the design of lane markings and signal timing settings for isolated intersections. The authors considered two objective

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functions namely: capacity maximization and cycle length minimization. Using different numerical examples, they concluded that their optimization method enhanced the intersection operation by increasing the reserve capacity up to 48%. Wong & Heydecker [4] extended the previous study by relaxing the numbers of approach lanes as new integer variables. The authors got the same result obtained from the previous study with an increase in reserve capacity up to 88% for 7-lane arms. However, the execution time for the simplest case they considered (4-lanes arms), was 60 s, which is relatively long from practical point of view. Other researches, discussed below, studied the relationship between lane group combination and the optimal cycle timing planes for a given traffic demand.

Ding et al. [5] developed a model to optimize lane use and signal timings for isolated signalized intersections with variable lanes and evaluated this model based on its ability in minimizing the intersection delay. They assumed that only one variable lane can be provided on each approach. The model was applied on a signal controlled four-way intersection with a variable lane in one approach. The minimum and maximum cycle length was assumed to be 60 s and 150 s respectively. They concluded that the proposed model can reduce the average delay and improve the efficiency of the intersection.

Zhang and Wu [6] analyzed the effects of DLA at one approach of a hypothetical isolated signalized intersection, assuming predefined demand levels and fixed cycle length of 120 s, using the objective function of minimizing the maximum saturation flow ratio. It was concluded that the DLA strategy improves the performance at the signalized intersection by reducing the average vehicle delay and number of stops. Wu et al. [7] made a study to evaluate the benefits of dynamic lane assignment strategy at an isolated intersection. The researchers used the same mathematical formulation and the numerical analysis of Zhang and Wu [6]. The researchers concluded that dynamic lane assignment strategy can reduce the intersection delay and number of stops. In addition, dynamic lane assignment has positive impacts on the environment, such as reducing gas emissions and energy consumptions even though they used a fixed cycle length and they applied the model at one approach only.

Li et al. [8] developed a dynamic lane use model at a four-approach signalized intersection that was subjected to fluctuation in demand, assuming that the total number of approaching lanes can be changed in consideration of the reversible lanes. The developed model was evaluated by VISSIM Simulation Software. It was concluded that the new model has a great effect on increasing the utilization ratio of time-space resources by optimizing lane-use assignment and signal phase plan simultaneously.

Najjar [9] conducted a study to investigate the effectiveness of applying DLA at a 4-approach signalized intersection. The researcher applied DLA at all approaches of the intersection accompanied with signal timing optimization, assuming a fixed percentage of right turn vehicles with a massive number of hypothetical percentages of through and left turning traffic at all approaches. He concluded that applying DLA along with signal timing optimization can enhance the performance of the signalized intersection by reducing the intersection delay.

The researchers in the above studies showed that applying DLA has a positive impact on the performance of signalized intersection in terms of increasing capacity, reducing delays and number of stops. Nevertheless, their studies were done based on many assumptions such as using fixed cycle length, ignoring the presence of shared lane and assuming that the demand variation will occur at one approach only.

The previous literature discussed above indicates that almost all the researchers concentrated on evaluating the benefits of applying DLA at signalized intersections. Nevertheless, no clear attempt was done to study the use of this concept throughout the day to serve fluctuation demand characteristics. Furthermore, the techniques available in the literature all depend on running algorithm for each specific turning movement demand and geometric characteristics. Very little attention was given to the method of identifying quickly the optimum lane group. This research tries to identify a practical quick method for identifying the optimal lane group combinations at any approach without the need of running any optimization algorithm.

3. Methodology

The objective of this research is to suggest a quick procedure to find the optimum lane groups for all approaches of a 4-approach intersection where each approach has green by itself in turn in the study area using the percentage of turning movements. This was achieved by developing massive hypothetical data sets of turning volumes (more than 600,000 data sets) for the typical intersection. For each set of the data, all possible lane groups for all approaches were considered in calculating the intersection delay. The lane group at each approach, which produced the minimum intersection delay, was considered as the optimum lane group for that specific data set of volume. Subsequently, the relationship between the percentages of turning movements and the optimum lane group was studied for the entire volume data set as shown in the following sections.

4. The DLA model

Few assumptions have been considered in building the DLA model as follows:

- The applied phasing scheme at the intersection is the geographical phasing scheme in which each phase is allocated for all movements (left, right and through) of one approach at the same time as shown in Fig. 1. This is the only phasing scheme allowed in the study area.
- The cycle length was selected by numerical search. The cycle length, which results in the minimum intersection delay for a specific demand, was selected as the optimal cycle length for this demand.
- Protected left turns. Only protected left turns are considered, as these are the only legal left turns in the study area.
- The principle of equal saturation flow ratio is used for shared lanes. According to this principle, the traffic demand is distributed between the lanes serving the same movement in a way to keep the volume-to-saturation flow ratios for these lanes nearly equal to each other.

In this study, the DLA model was developed to achieve an efficient intersection operation under a large variation in demand during the day. The objective function of the DLA optimization model is to minimize the average intersection delay per vehicle. To estimate the average intersection delay per vehicle, the proposed methodology by the Highway Capacity Manual HCM [10] was used. The average control delay per vehicle for a given lane is given by Eq. (1).

$$d_{i,k} = d_{1,i,k}(PF) + d_{2,i,k} + d_{3,i,k} \tag{1}$$

where:

- d: control delay per vehicle (*sec*);
- $d_{1,i,k}$: uniform control delay, assuming uniform arrivals for lane k at approach i (*sec*);
- PF: progression adjustment factor, assumed to be 1;
- $d_{2,i,k}$: average delay per vehicle due to random arrivals for lane k at approach i, which is called incremental delay (*sec*).
- $d_{3,i,k}$: average delay per vehicle due to initial queue at the start of the analysis time period for lane k at approach i (*sec*).

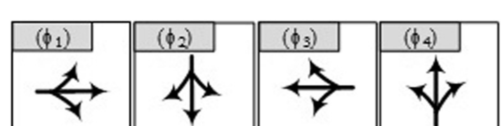

Fig. 1. Geographical phasing scheme.

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