Alexandria Engineering Journal (2016) 55, 2509–2514

HOSTED BY

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Estimating the minimum delay optimal cycle length based on a time-dependent delay formula

Ahmed Y. Zakariya *, **Sherif I. Rabia**

Department of Engineering Mathematics and Physics, Faculty of engineering, Alexandria University, Alexandria 21544, Egypt

Received 21 January 2016; revised 30 June 2016; accepted 11 July 2016
Available online 22 August 2016

KEYWORDS

Traffic signal control;
Time-dependent delay formulas;
Optimal cycle length;
Regression analysis

Abstract For fixed time traffic signal control, the well-known Webster's formula is widely used to estimate the minimum delay optimal cycle length. However, this formula overestimates the cycle length for high degrees of saturation. In this paper, we propose two regression formulas for estimating the minimum delay optimal cycle length based on a time-dependent delay formula as used in the Canadian Capacity Guide and the Highway Capacity Manual (HCM). For this purpose, we develop a search algorithm to determine the minimum delay optimal cycle length required for the regression analysis. Numerical results show that the proposed formulas give a better estimation for the optimal cycle length at high intersection flow ratios compared to Webster's formula.

1. Introduction

Traffic signal control is one of the most efficient methods to reduce the impact of traffic congestion. For an isolated intersection with fixed time signal control the cycle length is predetermined and fixed for all cycle in this intersection. The cycle length is selected to optimize the intersection performance. One of the most commonly used performance measures is the delay due to its direct relation to what drivers experience while attempting to cross an intersection [1,2].

A stochastic delay model was developed by Webster in purpose of estimating the overall vehicle delay [3]. Based on this model, Webster provided an estimate [4] of the optimal cycle length that minimizes the overall vehicle delay. A main consequence of Webster's delay model is that the estimated delays tend to infinity as the degree of saturation approaches one (the arrival flow rate approaches capacity) which is not true in the practical situation [4]. Hence, Webster's formula overestimates the optimal cycle length for highly-saturated intersections.

In order to enhance the performance of the stochastic delay model, time-dependent delay models were developed. As the degree of saturation approaches one, the delay computed from a time-dependent delay model becomes tangent to the deterministic over-saturation delay model [4]. These time-dependent models are widely used in capacity guides as in the Canadian Capacity Guide [5] and the Highway Capacity Manual (HCM) [6] to improve the estimate of the overall vehicles delay. However, a parallel line of improvement is missing which is estimating the minimum delay optimal cycle length based on the time-dependent delay models. To the best of our knowledge, such estimate has not appeared in the literature yet.

* Corresponding author.
E-mail addresses: ahmed.yahia@alexu.edu.eg (A.Y. Zakariya), sherif.rabia@alexu.edu.eg (S.I. Rabia).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.07.029
1110-0168

In [7], Al-Kubaisi aimed at developing a general regression model for the prediction of the optimal cycle length at signalized intersections depending on a simulation model. The data obtained from the simulation experiments are used in a linear regression analysis to achieve a model for the prediction of cycle length that minimizes overall vehicle delay. The optimal cycle length calculated by the regression model is compared to that calculated using the OSCADY/3 software. In [8], Cheng et al. used the HCS software [9] to conduct experiments for a typical four-phase intersection over wide range of traffic volumes and lost times. The results were used to generate an equation that modifies the original Webster's minimum delay cycle length equation.

In this paper, two regression formulas are developed to improve the calculation of the optimal cycle length compared to Webster's formula. In order to generate the data required for this regression process, a search algorithm is developed to locate the optimal cycle length based on a time-dependent delay model. Numerical results show that the proposed formulas give a better estimation for optimal cycle length at high intersection flow ratios compared to Webster's formula.

The rest of this paper is organized as follows. Section 2 presents the used time-dependent delay model. The search algorithm and the regression formulas are presented in Sections 3 and 4 respectively. Numerical results are shown in Section 5. Finally, concluding remarks are given in Section 6.

2. Time-dependent delay formula

Calculation of overall delay for each vehicle in this paper is based on a time-dependent delay formula as used in the Canadian Capacity Guide [5] and the Highway Capacity Manual (HCM) [6] with vehicular traffic flows expressed as the number of passenger car unit (pcu) per unit time.

The basic equation for estimating the average overall delay is

$$d = k_f d_1 + d_2, \tag{1}$$

where

- d: average overall delay (sec/pcu),
- k_f: progression adjustment factor ($k_f = 1$ for isolated intersection [5]),
- d_1: average overall uniform delay $= \frac{C\left(1-\frac{g_e}{C}\right)^2}{2\left(1-min(X,1)\ \frac{g_e}{C}\right)}$,
- d_2: average overflow delay $= 15t_e\left[(X-1)+\sqrt{(X-1)^2+\frac{240X}{c\,t_e}}\right]$,
- C: cycle length (sec),
- g_e: effective green time (sec),
- X: degree of saturation,
- c: capacity (pcu/h),
- t_e: evaluation time (min).

3. Search algorithm

An algorithm has been developed to find the optimal cycle length that minimizes the average delay by investigating an interval of cycle length $[C_{min}, C_{max}]$. C_{min} is defined [10] as the duration of time just long enough to allow all the traffic which arrives in one cycle to pass through the intersection in the same cycle. In this case, the intersection will be served at exactly capacity condition (degree of saturation = 1). Minimum cycle length could be expressed as [10]

$$C_{min} = \frac{L}{1-Y},$$

where

- C_{min}: minimum cycle length (sec),
- L: total intersection lost time (sec),
- Y: intersection flow ratio (sum of the critical lanes flow ratios).

C_{max} is the maximum cycle length which depends on practical limits. Long cycles involve long red intervals for some movements and, as a consequence, long delays for vehicles. A cycle length of 120 sec is usually considered as a practical upper limit [5], while 140 or 160 sec is used under exceptional conditions.

For each discrete value in this interval, we determine the total average delay for all vehicles in this intersection. Then, C_{opt} could be determined as the cycle length which provides the lowest total average delay. It is well known (see Fig. 3) that increasing the cycle length C, decreases the total average delay till C reaches C_{opt}, then total average delay starts to increase.

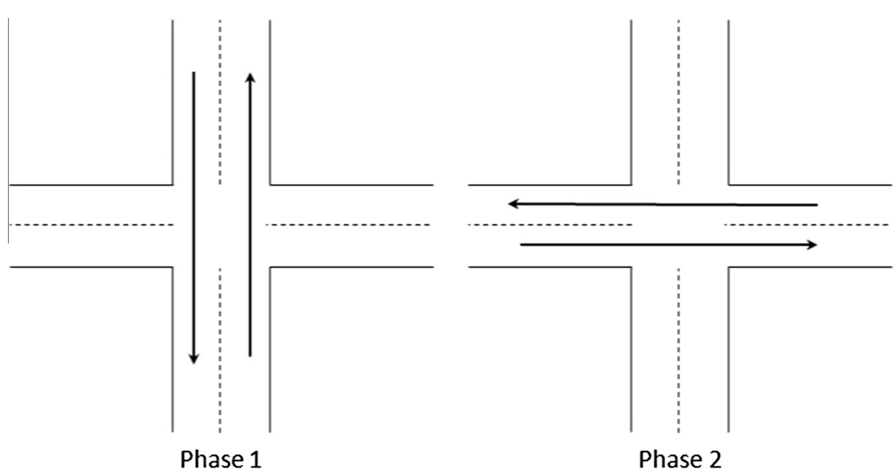

Figure 1 A two-phase, four-approach intersection.