■ 論 文 ■

Design of Maximum Green Time Parameters for Traffic Actuated Operation

감응식 신호운영을 위한 최대녹색시간의 설계

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목 차

Key Words : Traffic Actuated Control, Maximum Green Time Parameter, Average Green Time Estimation, Hybrid Genetic Algorithm, Simulation

요 약

감응식 신호운영변수 설계에 관한 연구는 정주기식 신호운영변수 설계의 그 것보다 그 수준이 현저히 미비하며 이는 감응식 신호운영 특성을 반영한 평가방법의 부재로 감응식 운영변수의 평가가 불가능하였기 때문이다. 본 논문은 최근에 소개된 평균 감응현시 녹색시간 추정 수리모형을 이용하여 Highway Capacity Manual (HCM) 지체도를 최소화하는 최대녹색시간의 설계방안을 제시한다 - '최소녹색시간'과 '단위연장시간'은 보행자 횡단시간 및 차량 차두시간 등 지역별 운전자/보행자의 특성과 관련이 있어 일반적인 최적화 설계 수리모형의 적용에 무리가 있어 제외한다. 제안된 설계방안은 감응식 운영논리를 토대로 감응현시 군의 평균녹색시간과 평균주기를 산정하며, HCM 지체도를 평가하고, 가능한 대안 중 지체를 최소화하는 최대녹색시간 운영변수 군을 '혼혈 유전자 알고리즘'으로 도출한다.

현장실험을 통해 도출이 불가능한 실제 최적치를 Corridor Simulation(CORSIM)모형을 이용하여 추정하였고 이를 제안된 설계방안으로 도출된 '최대녹색시간 운영변수' 값들과 비교하였다. 비교결과 교차로 v/c 비율이 1.0 보다 낮을 시는 제안된 방법을 통해 설계된 최대녹색시간 운영변수 군이 최소 CORSIM 지체도를 산출하는 최대녹색시간 운영변수 군과 동일한 것으로, v/c비율이 1.0보다 높을 시는 다른 것으로 결과되었다. v/c비율이 1.0 보다 높은 경우는 정주기식 교차로 운영에 효율적이라 감응식 운영의 필요를 벗어나므로 제안된 최대녹색시간 설계방안은 감응식 신호운영 필요범위 내에서 효율적이다. 기존의 최대녹색시간 설계는 정주기식 최적녹색시간을 기준으로 최대녹색시간을 추정하며, 그러한 과정을 돕기 위하여 추정범위(설계자가 범위 내에서 임의로 선택함)를 제시하는 것이 기존의 연구임을 비교하면 본 연구에서 제안하고 있는 설계방법의 의미가 크다.

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Ⅰ. Introduction

The traffic-actuated control is featured by the signal operation allowing green times to be adjusted in real time, based on the actuations from detectors buried on approaches. The length of a traffic-actuated phase is thus changed cycle by cycle, and the phase itself can be skipped when no demand exits. Due to such demand-respond abilities of control, the traffic-actuated controllers have been installed and utilized in a number of intersections in many nations.

A traffic-actuated controller requires a set of control parameters for the operation of a single phase. The control parameters for basic actuated operation include the minimum green time, the unit extension time and the maximum green time. The minimum green time is the minimum length of green time that should be displayed when a service call, a vehicle actuation, is received for the phase during the designed period. Unit extension time is the length of time that should be added to the green when an additional service call is received after the expiration of the minimum green time and before the expiration of the unit extension time. When no service call is received during the unit extension time, the green time terminates at the end of it, and it is called 'gap-out.' The maximum green time is the upper limit of the green time that a green time can maximally reach to. The green time also terminates when it reaches to the maximum green time.

For efficient traffic-actuated operation, designing the maximum green time parameter is especially critical since the parameter promotes the termination of green to shift the right-of-way to the next phase despite the continuous vehicle actuations during the green. The parameter can be designed in general problem solving domain, whereas the minimum green time and the unit extension time parameters should be designed based on the area specific drivers′ features and geometric conditions. The minimum green time and unit extension time should be designed based on the pedestrian crossing time and the average vehicle headway on an approach. The maximum green time, thus, is the highlighted parameter that should be in a system optimization procedure.

Many traffic engineers have developed the methods designing the proper range of the maximum green-time-parameter but failed to distinguish a specific parameter. Traffic engineers have studied a relationship between the pretimed optimal green time and the maximum green time parameter and suggested designing the maximum green time parameter based on the relationship. Many researchers addressed that the maximum green time should be longer than the pretimed optimal green. It should be noted that the design of the signal timing parameters for pretimed operation is based on the assumption of uniform vehicle arrival. The design of the signal timing parameters for traffic-actuated operation however is not based on the uniform vehicle arrival but based on the reaction of actuation varying cycle by cycle. The maximum green time should be longer than the optimal pretimed green to serve the vehicles arrived more than the average on cycle basis.

The existing design methods provide engineers in field with selecting a factor within a range they proposed, but the selection has been arbitrary. No method guiding to a certain number for the design of the maximum green parameter exists. This was because no method that designs the parameter based on the performance of the traffic-actuated operation was available.

In 1996, the traffic-actuated system performance evaluation based on its own mechanics became available due to the model introduced by the National Cooperative Highway Research Program (NCHPR) project numbered 3-48. The model estimates the average green time of an actuated phase. This NCHRP3-48 average green time estimation model was accepted by the HCM committee members and included in the 1997 and 2000 versions of the Highway Capacity Manual(HCM). The HCM proposes to evaluate a traffic actuated controlled intersection with the HCM capacity analysis method and the average green times estimated.

Due to availability of the performance evaluation model of a traffic-actuated system, it was motivated to design a set of maximum green time parameters by evaluating it and by searching for another set providing with better efficiency. This document describes a computational procedure that explicitly designs the maximum green time parameter based on (1) the average green times of traffic actuated phases, (2) the HCM performance evaluation procedure and (3) a searching method that finds the most efficient set of maximum green time parameters minimizing the overall average control delay at an intersection.

II. Background

The performance evaluation of traffic-actuated operation and the maximum green time parameter design methods were reviewed for the study. The pervious studies conducted in such topics are summarized below.

For the evaluation of traffic-actuated system performance, traffic engineers have directed their primary concerns toward better estimations of average green time and average cycle length. Earlier editions of the HCM suggested evaluating the performance of a traffic-actuated system should be based on an assumption that traffic use its green time under the traffic-actuated operation as efficiently as 95 percent of saturation(TRB, 1994).

However, Akcelik(1995) found that the actual v/c ratio of traffic-actuated system is less efficient than that. Akcelik and Chung(1995) developed a regression model based on simulation data to estimate the operational v/c ratio of actuated phases and found that the saturation of an actuated green is as low as 0.4 when approach volume is low. Based on that model, Akcelik(1995) suggested an iterative computational procedure that estimates the average green times and cycle lengths of traffic-actuated controllers. Courage et al.(1996) developed a method analyzing the capacity of a traffic-actuated system. They compared the results from their model to the simulation and field data and found that the R-square values to those are 0.90 and 0.95, respectively.

Kell et al.(1991) indicated that traffic engineers had arbitrarily determined the maximum green time within the range of 30~60 in practice and recommended that the maximum green parameters should be 1.25 to 1.50 times longer than the pretimed optimal green times. The method, however, does not design the parameter explicitly but a range. Lin(1985) verified the relationship between the average delay and the maximum green parameters based on simulation data. He suggested a method that could be used to design maximum green parameters based on different levels of the peak hour factor(PHF). His method is presented in Equation(1).

$$G_{\max} = \begin{cases} G_p + 10 & ,if \text{ PHF} = 1.00 \\ 1.8 \times G_p & ,if \text{ PHF} = 0.85 \\ 2.5 \times G_p & ,if \text{ PHF} = 0.70 \end{cases} \quad (1)$$

where,

$G_{\max}$: optimal maximum green time suggested by Lin

G_p : optimal green time for pretimed operation

He recommended using longer maximum green time when uncertainty exists. The method he proposed is relatively easy to implement; however, it still provides ambiguity, in model selection, because of the range of the PHF.

Courage et al.(1989) concluded through their study that the maximum green times should be somewhat shorter than proposed by Kell, Fullerton and Lin. They indicated that the maximum green parameters have little or no impact on the performance of the traffic-actuated system when traffic volume is low, while they become significant when traffic volume increases. Orcutt(1993) suggested setting maximum green time long enough to serve 1.3 times the average queue length in order to accommodate the peak volume during the period of maximum green. However, he failed to determine the most efficient cycle length for the traffic-actuated system. It also was proposed that maximum green should be in the range of 20 to 30 seconds and should not be shorter than 15 seconds. He suggested that there be at least a 5 second gap between minimum and maximum green times.

A method that estimates the average length of an actuated phase was introduced through the National Cooperative Highway Research Program project 3-48. The method was accepted by the Highway Capacity Committee and proposed being used in the performance estimation of traffic-actuated phases with the HCM capacity analysis methodology(TRB, 2000). This method will be referred to "the HCM average green time estimation method" in this document. The capacity analysis procedure for the actuated system becomes as surefooted as the one for pretimed control due to the method.

The average green time of a traffic-actuated phase is estimated by dividing a green time into two different portions in the HCM average green time estimation method: queue service time and green extension time. Kim(2002) found that the underestimate tendency of the HCM average green time estimation model and propose a new average green time estimation model. He progressed the estimation of the queue service time by including an additional portion of queue service time excluded in the HCM model. The additional queue service time is a green time portion starting from the queue clearance time and ending at the time that last vehicle at the end of queue passes the detection area. His method will be referred to "the revised HCM average green time estimation method" in this document. The average green times estimated by the revised HCM method were compared to the CORSIM simulation data surrogating field data, and it was found that the model estimate the average green time of exclusive movement only case and the shared permitted left-turn involved case with the R2 values of 0.98 and 0.90, respectively.

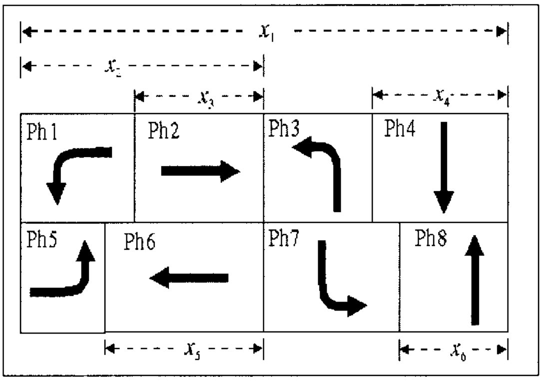
Enhanced Value Iteration Process Actuated Signals (EVIPAS) is a computer-based model that exhaustively searches entire feasible sets of possible combination of solutions based on simulation(Bullen et al., 1987). However, it has not been widely used because of its inefficiency: complex input requirement and its long execution time(Courage, 1996). SYNCHRO is another program that designs the maximum green time parameters. It does not explicitly design the parameters but determines those by splitting a cycle length without considering mechanics of traffic-actuated operation(Hunch, 1998).

Ⅲ. Design of the Maximum Green Time Parameters

The proposed maximum green time parameter design procedure consists of four components: (1) estimation of the average green time of an traffic-actuated phase, (2) performance evaluation of the system, (3) a formulation of overall average control delay minimization problem and (4) a searching. For the estimation of the average green time, the revised HCM average green time estimation method was employed. The 2000 HCM capacity analysis methodology was employed for the evaluation of an intersection with the average green times estimated. Based on such evaluation procedures, a formulation for the overall average control delay minimization and a searching method were developed. The optimization formulation and the searching method designed to find the solution are presented in the following sub sections.

1. Optimization Formulation

An optimization problem was formulated to design the maximum green time parameters for the strategy of the overall average control delay minimization. The six independent variables were set based on dual-ring phase scheme. The variables used in the objective function are illustrated in ⟨Figure 1⟩.



⟨Figure 1⟩ Independent variables designed for the dual-ring phase scheme

An objective function represents the average control delay of all vehicles entering an isolated intersection. The control delay is the one that would be removed when a signal is removed from the intersection (TRB, 2000). The constraints were designed based on the mechanics of dual-ring phase operation:

$$\text{Minimize} \quad \frac{\sum_{i=1}^{8} v_i d_i(x_1, \cdots, x_6)}{\sum_{i=1}^{8} v_i} \qquad (2)$$

subject to

$x_1 \geq x_2$,

$x_2 \geq Max\left[\sum_{i=1}^{2}\left(G_i^{\min} + I_i\right), \sum_{i=5}^{6}\left(G_i^{\min} + I_i\right)\right]$,

$x_1 - x_2 \geq Max\left[\sum_{i=3}^{4}\left(G_i^{\min} + I_i\right), \sum_{i=7}^{8}\left(G_i^{\min} + I_i\right)\right]$,

$x_2 - x_i \geq 0$, for i=3 and 5,

$x_1 - x_2 - x_i \geq 0$, for i=4 and 6,

$x_2 - x_{3+(i-1)/2} > G_i^{\min} + I_i$, for i=1 and 5,

$x_1 - x_2 - x_{3+(i-1)/2} > G_i^{\min} + I_i$, for i=3 and 7,

$x_i > G_i^{\min} + I_i$, for i= 3, 4, 5 and 6,

$x_i - C_{\min} \geq 0$, for $\forall i$,

$C_{\max} - x_1 \geq 0$, for $\forall i$,

$x_i \geq 0$, for i=1,⋯,5 and 6.

where,

x_i : decision variables(see ⟨Figure 1⟩)

v_i : traffic volume of the movement assigned to the dual-ring phase i

d_i : control delay of the movement assigned to the dual-ring phase i

$G_i^{\min}$: minimum green time of the dual-ring phase i

I_i : intergreen time of the dual-ring phase i

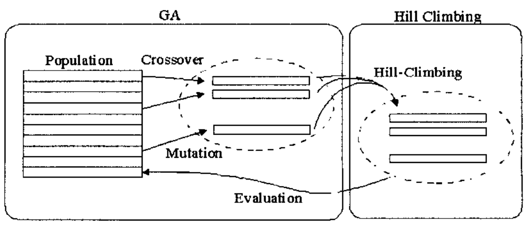
$C_{\min}$: minimum cycle length

$C_{\max}$: maximum cycle length

2. A Searching Method

The Hybrid Genetic Algorithm(HGA) was designed for searching. HGA is the combination of Genetic Algorithm(GA) and the scaled hill-climbing search method and is illustrated in ⟨Figure 2⟩. The HGA method used in this study is a combination of the previous HGA studies conducted by electrical engineers and the scaled hill climbing method designed by the author.

GA generally requires long computation time despite of its powerful capability of obtaining a global optimal solution(Fu, 1994). Hill-climbing searching method provides fast arrival to the optimal point, but it has a problem with local optimal solution. By using HGA, the converging time of



⟨Figure 2⟩ The structure of HGA

GA should be reduced due to the assistance of the hill-climbing method. In addition, GA should eliminate the local optimum problem of the hill-climbing method.

The conventional GA requires three computational modules: representation, crossover and mutation. The HGA in the proposed method employs a real number encoding scheme for representation, arithmetic operators for convex crossover and a dynamic mutation operator for mutation. The following describes those modules implemented in GA and the scaled hill-climbing method developed for this study

1) Real Number Representation

The proposed computational procedure employs a real number representation scheme. The conventional GA uses an operator that utilizing a set of binary codes to represent the chromosome of a decimal number. The real number representation scheme increases the speed of the searching by avoiding a converging process required by the conventional method for encoding and decoding binary codes to decimal numbers and vice versa.

2) Crossover

For the crossover operation, an arithmetical operator was used. An arithmetical operator is the one formulated based on convex set theory(Gen, 1989). With this operator, offsprings are defined as the weighted average of two parent vectors. Let's denote the parents as v_1 and v_2. Their offsprings are computed as follows:

$$v_1^{new} = \lambda v_1 + (1-\lambda)v_2 \text{, and} \tag{3}$$

$$v_2^{new} = \lambda v_2 + (1-\lambda)v_1 \tag{4}$$

where, λ : a weight factor

By setting the range of λ as $0 < \lambda < 1$, the crossover operation was set to be in a convex hull. The convex crossover was employed in this study by setting λ as 0.38, which introduces the golden section (1:1.618) of the convex hull.

3) Dynamic Mutation

Dynamic mutation was employed. This operator is designed for fine tuning capabilities aimed at achieving high precision. Two operators are defined(see Equations(5) and (6)). Let's denote the selected element for mutation as x_k. When mutation occurs, the active operator would be either Equation(5) or Equation(6) based on a random number drawn.

$$x_k^{new} = x_k + \Delta\left(t, x_k^U - x_k\right), \text{ or} \tag{5}$$

$$x_k^{new} = x_k - \Delta\left(t, x_k - x_k^L\right) \tag{6}$$

where,

x_k^U : upper bound for x_k

x_k^L : lower bound for x_k

$\Delta(t,y)$: $y \cdot r \cdot (1 - t/T)$

r : a random number within the range of [0,1]

t : generation (iteration) number

T : target generation number.

The function Δ returns a value within the range of [0, y], and the value approaches zero when t increases. It makes the mutation operator generate a mutant that can be anywhere in a whole feasible area when the number of iterations is small. When the number of iterations becomes large, mutation occurs locally.

4) Scaled hill climbing

In the hill-climbing search, its step size plays an important role. When the step size is small, the expected number of iterations required to reach the optimum would be increased, and more chances to converge to the local optimum would be provided. On the other hand, when the step size is large, the searching speed becomes fast, but it only provides with a coerce estimation of the optimal solution.

For efficient performance of the hill-climbing search, the scaled hill-climbing search method was developed by the author. In the scaled hill-climbing search method, the step size was designed to vary over the searching process. Let's denote k be a step size of the hill-climbing search. Then:

$$k = k_{\min} + \left(\frac{h - 0.37}{1.63 - 0.37}\right)\cdot\left(k_{\max} - k_{\min}\right) \qquad (7)$$

where,

$$h = \begin{cases} 2 - \exp[-(x-u_0)/(u_1-u_0)], & \text{when } x < u_0 \\ \exp[-(x-u)/(u_2-u_0)] & \text{, when } x \ge u_0 \end{cases}$$

$k_{\min}$: minimum step size

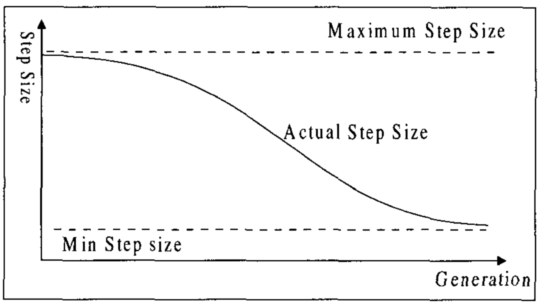
$k_{\max}$: maximum step size

u_1 : minimum generation number, 1

u_2 : maximum generation number, target generation and

u_0 : middle point between and u_2

It was intended to increase the speed by searching the feasible space with the large step size at the initial stage, and the size becomes smaller than that at the latter stages(see ⟨Figure 3⟩).



⟨Figure 3⟩ Scaled hill climbing method

Ⅳ. Tests and Comparisons

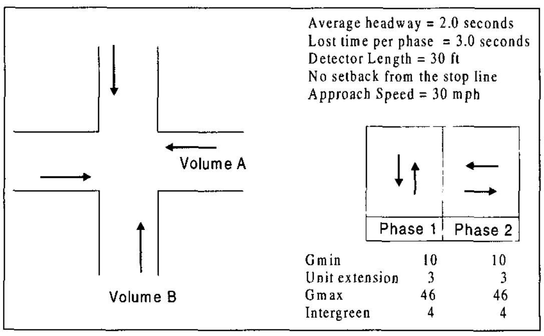
It is valuable to compare the maximum green time parameters designed based on the proposed procedure and the real optimum. Since it is impossible to find the true optimal solution in field due to the turbulences in traffic conditions and saturation flow rate, the CORSIM simulation data were employed to surrogate the field data, and sets of parameters minimizing the overall average control delay were found through exhaustive search.

The hypothetical intersection(see ⟨Figure 4⟩) presented in the final report of the NCHRP 3-48 project was employed to test the performance of the proposed design method. Four different traffic conditions were designed based on the geometric condition. They are 675, 780, 820 and 900 vehicles per hour per lane(vphpl).

Based on those geometric and traffic conditions, the maximum green time parameters were designed with the following methods:

1. CORSIM based exhaustive searching
2. Proposed method(HCM based)
3. Lin's method
4. Kell and Fullerton's method

The maximum green time parameters found by the design methods(method 2, 3 and 4) were compared with the CORSIM optimal(method 1) surrogating the field optimal. CORSIM is a simulation program developed through various research studies under the supervision of the Federal Highway



⟨Figure 4⟩ The hypothetical intersection used for the test of the NCHRP method

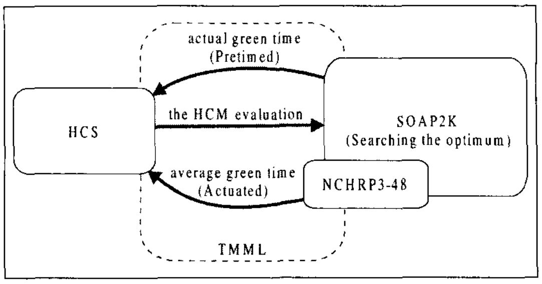
Administration(FHWA) over a period of twenty years. It is a microscopic model that simulates traffic on freeway and network facilities controlled by various types of traffic controls. The program has been validated and widely implemented in various traffic studies. The model does not provide any optimization routines for signal timing parameters, but it provides reliable simulation results(Chundury et al, 2000).

CORSIM is the program containing a dual-ring based FORTRAN traffic-actuated control module used in the NEMA local controllers in field. Thus, the mechanic of dual-ring operation used in CORSIM is identical to the one used in field.

A simple two-phase dual ring operation was employed for the test to illustrate three-dimensional graphs for the visualization of the changing trend of overall average control delay over the variations of maximum green time parameters. The proposed procedure is valid with the eight-phase dual ring operation as long as the identical constraints are used in the optimization formulation.

1. Automation of the Proposed Design Method

A program was coded with the Visual Basic computer programming language to assist the implementation of the proposed design method, and it was named SOAP2K. It contains (1) the functionality to estimate the average length of an actuated phase based on the revised average green time estimation model and (2) the ability to communicate with the performance evaluation module, Highway Capacity Software(HCS), which is the program developed for the automation of the HCM evaluation procedure at the University of Florida under the supervision of FHWA. The computer-based computation structure of SOAP2K designed for the automation of the proposed design method is presented in ⟨Figure 5⟩. SOAP2K also has the functionality to find the HCM optimal pretimed green time since it possesses the ability to communicate with HCS and searcing.



⟨Figure 5⟩ The structure of the proposed computational procedure

2. Finding the Maximum Green Time Parameters

In the CORSIM analysis, the maximum green time parameter was varied from 15 to 100 seconds by increasing 5 seconds for both phases. Total 324(18×18) combinations of maximum green time parameters were tested for a given traffic condition. At least 3,240 CORSIM runs were made through the following rule for each of traffic conditions considered.

Multiple CORSIM runs were made with a different set of random seed numbers for a single analysis. First, 10 initial analyses were made. When the standard deviation of the 10 different average phase lengths from those is less than or equal to the 10 percent of the overall average, the simulation process was terminated. If not, the sample size, the number of CORSIM runs, was increased by adding 10 more runs with newly introduced random seed numbers.

For the GA computation, the population size, the crossover rate, the mutation rate and target generation are set to 10, 0.4, 0.1 and 10, respectively. For the scaled hill-climbing computation, the maximum and minimum step sizes are set to 5 and 1, respectively.

To design the parameters based on Lin's and Kell and Fullerton's methods, it is required to design the pretimed optimal green times. Through the overall average control delay minimization strategy, the pretimed green time was computed with SOAP2K. The optimal pretimed green times for designed traffic conditions are 20, 28, 30 and 46 seconds, respectively.

For Kell and Fullerton's method, the expansion factor of 1.25 and 1.50 were used. They are the lower and upper limits of the range they suggested. For Lin's method, ten more seconds were added to the pretimed green time since the PHF is 1.00.

V. Results

In order to visualize the optimality of the design value, the delay-changing trend over the changes of the maximum green time parameters was plotted in three dimensions through SOAP2K(see 〈Figure 6〉). The horizontal axles represent maximum green times, and the vertical axle represents the average control delay, computed based on overall average control delay. The scales of the axles were set to identical for graph (a) and (b), (c) and (d), (e) and (f), and (g) and (h), respectively, for the comparison purpose.

The differences between the CORSIM delay and the HCM delay are from the two different approaches to estimate the control delay: the analytical and simulation models. In addition, the difference of the maximum green times at 900vph between CORSIM and the proposed method is due to the performance of the HCM delay model for oversaturated conditions.

〈Figure 6〉 indicates that the outputs from the proposed method are the truly identical to the CORSIM optimal when volume-to-capacity ratio(v/c) is less than 1.0. The optimal maximum green times designed by the proposed method are 20, 30, 35 and 45 seconds when traffic volume is 675, 780, 820 and 900vphpl. The volume of 900vphpl yields the oversaturated condition since 1800vphpl of the saturation flow rate and 3 sec of lost time per phase were considered in th study. The difference of the maximum green times between CORSIM and the proposed method at 900vphpl is because of the performance of the HCM delay model for oversaturated conditions.

The CORSIM simulation results showed that, when the v/c ratio becomes larger than one, the maximum green time parameter should be increased steeply. In practice, however, the pretimed operation is appropriate when v/c ratio is higher than 1.0. Thus, the proposed method works effectively in the boundary of interest of traffic actuated operation.

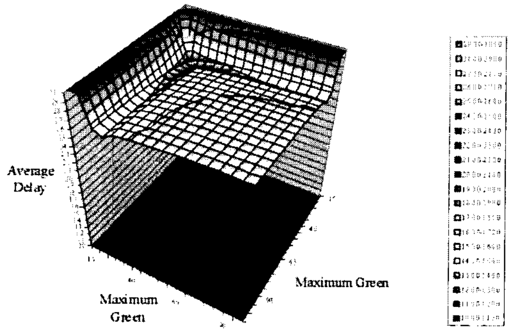
Comparison between the maximum green time parameters designed by the existing models and the proposed procedure were made, and the results are summarized in 〈Table 1〉. The results show that the proposed method, a combination of the HCM-based evaluation and the HGA method, explicitly finds the simulation-based optimal maximum green time parameters. The other methods were not capable of finding the optimal parameter explicitly, and the ranges which they suggested to choose the maximum green parameters from exclude the simulation optimal.

Ⅵ. Conclusions

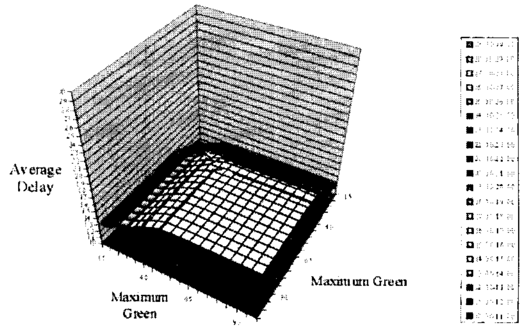
The maximum green time design procedure proposed in this paper is comparable to the one used in the design of pretimed green time. It designs the maximum green parameters based on the HCM evaluation with the average green times estimated by the revised HCM model.

The maximum green time parameters designed for different traffic conditions by the proposed method were compared with the CORSIM optimum surrogating the field optimum and the ones from the existing methods. The following summarizes the finding and conclusions:

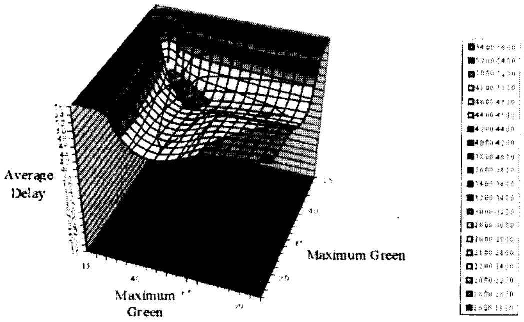
1. The maximum green time can be explicitly designed whereas the existing methods ask traffic engineers in field to select a number arbitrarily within a certain range.



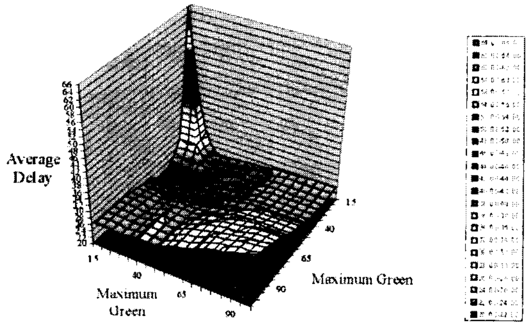
Optimal maximum Green Times=20, 20
(a) Proposed method with 675vphpl



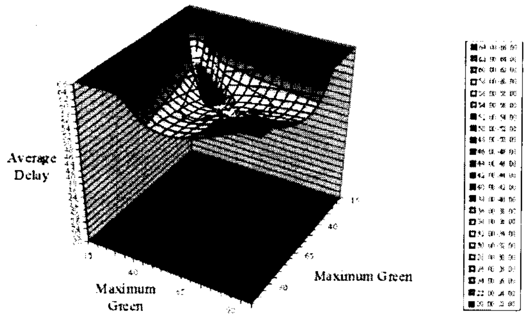
Optimal maximum Green Times=20, 20
(a) CORSIM with 675vphpl



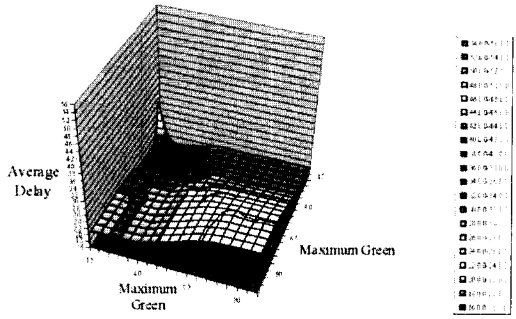
Optimal maximum Green Times=30, 30
(c) Proposed method with 780vphpl



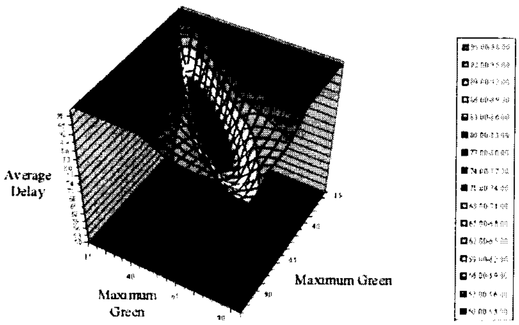
Optimal maximum Green Times=30, 30
(d) CORSIM with 780vphpl



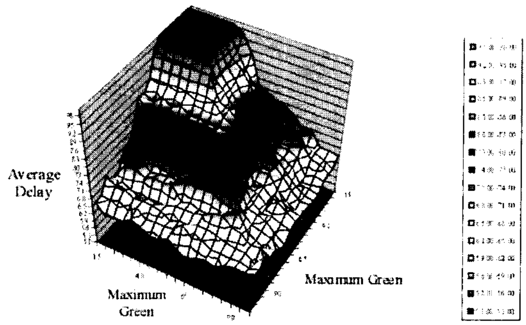
Optimal maximum Green Times=35, 35
(e) Proposed method with 820vphpl



Optimal maximum Green Times=35, 35
(f) CORSIM with 820vphpl



Optimal maximum Green Times=45, 45
(g) Proposed method with 900vphpl



Optimal maximum Green Times=95, 95
(h) Proposed method with 900vphpl

⟨Figure 6⟩ Comparison of the proposed optimal and the CORSIM optimal maximum green time parameters

〈Table 1〉 Comparison of the maximum green time parameters designed by different methods

Methods	Approach volume			
	675	780	820	900
CORSIM Optimal	20	30	35	95
Proposed Method	20	30	35	45
Lin	30	38	40	56
Kell and Fullerton	25~30	35~42	38~45	58~69

2. It was demonstrated that the parameters designed by the proposed method are identical to the simulation optimal surrogating the field optimal, when v/c ratio is less than 1.0.
3. When v/c ratio is higher than 1.0, the proposed method is not able to design the maximum green time parameter due to the limitation of the HCM delay equation.
4. However, the proposed method is valuable for designing the parameter for traffic-actuated operation since the pretimed operation is appropriate in practice when v/c ratio is higher than 1.0.

The following enhancements were introduced through this study to the current status of traffic engineering. The design of the maximum green time parameters for efficient traffic actuated operation has been shifted from the rough estimation form the pretimed optimal green time to the one based on the traffic-actuated system performance evaluation, which is theoretically and surely footed.

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