Overflow Delay Estimation for a Simple Intersection with Fully Actuated Signal Control

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Queueing delay at a traffic signal can be generally estimated as the sum of two components, uniform and overflow. The delay formula in the 1985 *Highway Capacity Manual* (HCM) applies primarily to lane groups under pretimed control. Although the HCM contains a method for estimating cycle length and splits under vehicle-actuated operation, the resulting effect on delays has yet to be verified. Furthermore, the HCM assumption of "snappy" operation and its inability to compare pretimed and actuated control have been criticized in the literature. An approach for estimating overflow delays for lane groups under vehicle-actuated control using the current HCM delay model format is presented. An existing cycle-by-cycle simulation model has been modified to produce delay for a basic vehicle-actuated signal operation. Overflow delay is computed as the difference from total simulated delay minus estimated uniform delay for the average cycle conditions. The results indicate that the average cycle and overflow delays are very much related to the controller settings such as minimum and maximum greens and cycles and unit extensions, with longer unit extensions producing higher cycle length and overflow delay. Furthermore, applying the 1985 HCM formula to the simulated signal settings resulted in much higher delays, which implies the need for separate calibration of the second delay term to account for the actuated control effects. The simulation model was executed to produce a calibration data base for an analytical overflow delay model.

In many traffic signal installations, the two most common types of intersection control are pretimed and vehicle actuated. In fact, some modern controllers can implement any combination of both controls depending on the level of traffic demand and the need to provide signal coordination. Actuated control schemes are typically classified into semiactuated, fully actuated, and volume-density control (*1*). In all schemes, phase green time is allocated to the different movements on the basis of the prevailing traffic demand. The three actuated control schemes vary in the amount of detectorization and in the establishment of criteria for phase termination (*1*). In contrast, pretimed control is established on the basis of average demand and, therefore, is often unable to respond adequately to random fluctuations in traffic volumes and demand variations on a cycle-by-cycle basis.

To establish capacity and level of service (LOS) impacts of actuated control operation, the 1985 *Highway Capacity Manual* (HCM) provides recommendations in Appendix 2 of Chapter 9 regarding the method for estimating the "average" cycle length and green splits in the peak 15-min period (2). This step is critical to the operational analysis procedure since signal timing settings are known for neither existing (barring actual field observations) nor projected conditions. These estimates are subsequently used to produce stopped delay and LOS.

Two fundamental issues arise in the HCM estimation process: (a) how realistic are the estimates of average cycle and splits for actuated control? and (b) is the current HCM delay equation, and in particular the overflow delay term, valid for both pretimed and fully actuated control, or are separate calibrations warranted? In this work, the focus is on the latter. Results from the literature are also presented that shed more light on the first issue.

The analysis presented in this paper applies to a basic vehicle-actuated signal controller that uses a fixed-time extension (gap time) setting and passage detection. A detailed analytical treatment of this type of controller as well as more sophisticated modern controllers that use gap-reduction and various density techniques is presented by Akçelik (*3*).

REVIEW OF 1985 HCM METHOD

Stopped delay is the principal performance measure for assessing the LOS of signalized intersections. In the case of fully actuated signalized lane groups, the average approach delay per vehicle in the 1985 HCM can be estimated according to the following:

$$d = (d_1 + d_2)\,\mathrm{PF} \tag{1}$$

$$d_1 = \frac{0.5C_{av}(1 - \lambda_{av})^2}{(1 - \lambda_{av} X_{av})} \tag{2}$$

$$d_2 = 900\, TX_{av}^2 \left[(X_{av} - 1) + \sqrt{(X_{av} - 1)^2 + \frac{mX_{av}}{QT}} \right] \tag{3}$$

where

- d = average approach delay per vehicle;
- d_1 = average uniform delay per vehicle;
- d_2 = average overflow delay per vehicle;
- PF = progression factor;
- C_{av} = cycle length (sec);
- λ_{av} = g/C, ratio of effective green to cycle length;
- X_{av} = v/c, degree of saturation, ratio of arrival flow rate to capacity;
- m = calibration parameter (m = 4 in 1985 HCM);
- Q = capacity [vehicles per hour (vph)]; and
- T = flow period (hr) (T = 0.25 in 1985 HCM).

The progression factor PF = 0.85 reduces the queueing delay to account for the more efficient operation with fully actuated opera-

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tion when compared with isolated, pretimed control. In upcoming revisions to the HCM Chapter 9 procedures, the progression factor will be applied to the uniform delay term only. Finally, stopped delay, d_s, can be estimated using the approximation $d_s = d/1.30$.

Because delay estimation requires knowledge of signal timings in the average cycle, the HCM provides a simplified estimation method. The average signal cycle length is computed from

$$C_{av} = \frac{LX_c}{X_c - \sum (v/s)_{ci}} \quad (4)$$

where X_c equals critical volume-to-capacity (v/c) ratio under fully actuated control ($X_c = 0.95$ in HCM). For the critical lane groups (ci), the effective green

$$g_i = (v/s)_{ci}(C_{av}/X_c) \quad (5)$$

where s is the saturation flow rate.

Two major differences emerge between the estimation of delays for pretimed and fully actuated lane groups. In the latter, delays are reduced by 15 percent to account for the more efficient operation at the same v/c ratios. More important, the design v/c ratio, X_c, for lane groups under actuated control is higher than that of a comparable pretimed controller. This is the result of the typically shorter phase lengths associated with actuated control, in which right of way is transferred to the conflicting phases soon after the queue dissipates or demand for a conflicting phase preempts the current phase. On the other hand, the lower X_c for pretimed control is meant to provide a margin of safety to accommodate short-term variations in demand.

The assumption of "snappy" operation has been the subject of criticism in the literature. Lin, for example, compared the predicted cycle length from Equation 4 with field observations in Upstate New York (*5*). In all cases, the observed cycle lengths were higher than predicted whereas the observed X_c ratios were lower. Tarnoff (*6*) simulated the operation of fully actuated controllers in NETSIM (*7*). He found that delays were sensitive to and increased with the controller's unit extension, an indication that snappy operation may well depend on the actual controller's parameter settings. The association between delays and controller's parameter settings was also pointed out independently by Akçelik (*8*), Santiago (*9*), and Skabardonis (*10*). In a recent paper, Akçelik (*3*) derived a cycle length formula for vehicle-actuated signal control allowing for minimum and maximum green time settings.

Finally, the proposed delay model in Equation 1 appears to violate a well-known principle in signal systems control: basic fully actuated controllers (i.e., with no skip phasing or gap reduction features) behave as pretimed controllers under very light or very heavy traffic flow conditions. Under light flow conditions, phase green times are dictated by the controller's minimum greens; under heavy flow conditions, all phases "max out." An examination of Equation 1 reveals that regardless of demand level, the actuated controller always outperforms its pretimed counterpart. In reality, delays will be similar between the two types of control for very high and very low v/c ratios assuming that the minimum and maximum signal timing parameters for the actuated control case are equivalent to those for the fixed-time controllers. For intermediate flow conditions, delay benefits can be expected with actuated control, and only when the controller parameters are set properly. This problem is addressed to a certain extent in the revised Chapter 9 method. In this revision, a delay factor is applied to the first (uniform delay) term only, and thus overall delays for pretimed and actuated operation will tend to converge at high v/c ratios, since the second term governs in that region.

In recognition of the existing deficiencies in the 1985 HCM with regard to actuated control operation, NCHRP has initiated a research project to address many of the stated problems (*11*).

METHODOLOGY

Delay Model Framework

The proposed approach uses the delay model format in the 1985 HCM (Equation 1) to estimate delay under fully actuated control, with some notable variations to both the uniform and overflow delay terms.

1. The progression factor is taken out of the formulation of delay model. Since the objective is to study the effect of signal settings on delay estimates, the first term is considered to be identical to the pretimed control, except that it uses the average rather than the fixed signal settings. The effect on the second term is considered in the calibration term m ($m = 4$ and $T = 0.25$ in 1985 HCM Equation 3), as discussed earlier.
2. The multiplier X^2 is taken out of the formulation of the overflow delay term. This is consistent with previous comments regarding the desirability of convergence at high v/c ratios for all types of control. By eliminating this term, the relationship between the steady-state and the time-dependent forms of the delay model using the coordinate transformation method (*12,13*) is preserved. [For more details on this issue, see the work by Akçelik (*3,8,14,15*) and by Akçelik and Rouphail (*16,17*).] Finally, the proposed form allows for direct comparison of the resultant delay models with their pretimed counterpart, calibrated in previous work (*4,18*).

To summarize, the steady-state form of the overflow delay model is derived from the principles of queueing theory, assuming a generalized service time distribution, and a random arrival distribution

$$d_2 = \frac{kX}{Q(1 - X)} \quad (6)$$

where k is a calibration parameter and Q is the lane group capacity. The corresponding time-dependent formulation of the model given in Equation 6, obtained by using the coordinate transformation method, is

$$d_2 = 900T\left[(x - 1) + \sqrt{(X - 1)^2 + \frac{mX}{QT}}\right] \quad (7)$$

of which Equation 3 is a special case with $m = 4$, $T = 0.25$ hr, and the X^2 term is deleted. A detailed treatment of the subject of the coordinate transformation is outside the scope of this paper. Interested readers are referred elsewhere (*12,13*). Akçelik (*14*) noted that the parameters k in Equation 6 and m in Equation 7 are related such that $m = 8k$.

Simulation Model

An existing discrete, macroscopic dynamic cycle-by-cycle simulation model has been adapted to model timings and delays at an intersection with two single-lane approaches and two-phase basic fully actuated control. Vehicles are represented as individual (discrete) entities, but delays are computed for groups of vehicles having the same properties (hence macroscopic). Details of the model operation and assumptions under pretimed control at isolated intersections have been discussed in a recent paper (*18*). Here, the authors focus on the variations that were implemented to model actuated control operation.

Vehicle Generation

Because cycle and green times are unknown, the simulated number of arrivals per cycle cannot be determined a priori. In the revised model, arrivals were estimated on the basis of the maximum controller settings for the purpose of establishing an arrival flow rate in each cycle. The arrival rates are then used to determine the appropriate phase lengths.

Basic Phase Length

The basic green time in Cycle i needed to discharge the initial queue as well as the new arrivals in this cycle is estimated from

$$g_{ib} = \frac{\mathrm{EOQ}_{i-1} + v_i r_i}{S_i - V_i} \tag{8}$$

where

EOQ_{i-1} = queue length at end of Cycle $i - 1$,
v_i = average arrival rate during Cycle i,
r_i = effective red in Cycle i, and
s_i = saturation flow rate for approach lane during Cycle i.

In other words, the basic green time g_{ib} is equivalent to the saturated portion of the green period.

It is cautioned that while Equation 8 assumes a fixed saturation flow rate, normal variations in queue discharge headways could lead to the premature termination of the phase, particularly when short unit extensions are used. This possibility is not accounted for in the development of the delay models presented here, but it can certainly affect their validity and limit their applicability. Further work on incorporating this effect in the simulation model is planned.

With a two-phase controller, the effective red r_i is equivalent to the effective green of the competing phase plus the total lost time in the cycle (L).

Actual Phase Length

Although in theory the right of way should yield to a competing movement as soon as the basic phase length expires, in reality the green time is extended as long as vehicles are detected at headways that are shorter than the preset unit extension. This assumes, of course, that neither the minimum nor the maximum settings apply. This green extension is, therefore, dependent on both the prevailing headway distribution and the unit extension. For a single-lane case it may be reasonably assumed that headways follow the shifted negative exponential distribution, with a mean headway of $1/v_i$, v_i = arrival flow rate in vehicles per second, and a minimum headway of Δ. When the green extension is measured from the time that the basic green ends, this extension is equivalent to the length of a block of consecutive headways each greater than or equal to the unit extension, followed by a headway greater than the unit extension. Thus, at a minimum, the green will be extended by one unit extension.

Define this green extension for cycle i as E_i. It can be shown that, under the stated assumptions, the average E_i can be estimated from probability theory as

$$E_i = -\left(\frac{1}{v_i} - \Delta\right) + \frac{1}{v_i} e^{\frac{UE-\Delta}{1/v_i - \Delta}} \tag{9}$$

This relationship is depicted graphically in Figure 1 with $\Delta = 2$ sec. It is shown that the higher the unit extension, the more sensitive is the extension time to the prevailing volumes.

To summarize, the phase length for cycle i in the simulation model is expressed as

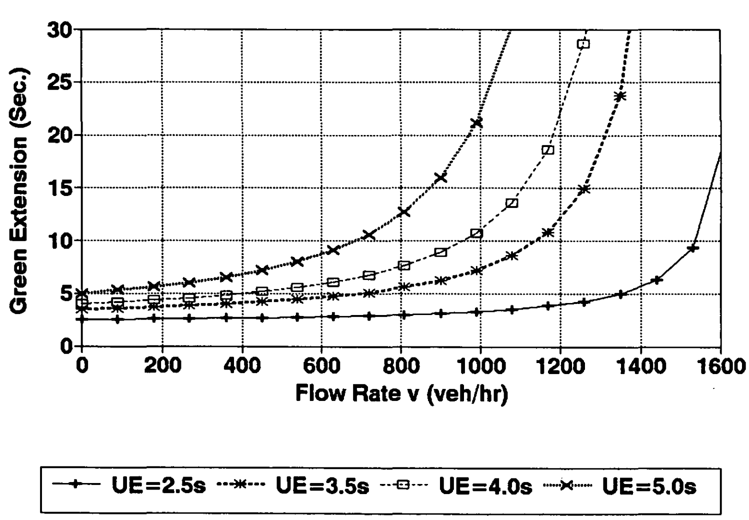

FIGURE 1 Extension green time E_i for indicated flow rate and unit extension.

$$g_i = g_{ib} + E_i = \frac{\mathrm{EOQ}_{i-1} + v_i r_i}{s_i - v_i} + E_i \qquad (10)$$

The effective phase green g_i is subject to constraints on minimum and maximum greens, which are either internally computed (assuming typical detector setback, speed limit, and unit extension) or entered as input into the simulation model. The cycle length is readily derived as $(r_i + g_i)$ for two phase operation. Note that g_i for the just-completed phase, when added to the lost time per cycle, constitutes the current effective red time for the competing phase. The process is then repeated for the competing phase and reverts back and forth between the two phases until the simulation time expires. A sample output of the simulation is provided in Figure 2. For this study, the minimum headway Δ is set to 2 sec for all simulation runs.

SIMULATION RESULTS

Signal Settings

Figures 3 and 4 depict the simulated cycle length and effective green times over a 2-hr simulation run. In both cases, the minimum green was set at 18 sec, maximum green at 56 sec, and unit extension at 2.5 sec. Equal flows on both approaches were simulated. In Figure 3 the resulting average *v/c* ratio is 0.86, whereas in Figure 4 it is 0.94 (both are less than the HCM's 0.95). The simulated cycle length and green exhibit a large degree of randomness, not too dissimilar in pattern from the field observations gathered by Prevedouros (*19*). In Figure 4 it is evident that many cycles and green times are reaching the maximum settings much more frequently than those depicted in Figure 3.

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              MAJOR FLOW STATISTICS FOR 2 SIMULATED HOURS

**** INPUT ECHO DATA ****

MINIMUM CYCLE LENGTH       =   44       MAXIMUM CYCLE LENGTH    =  120
CONTROLLER UNIT EXTENSION  =   2.5      SATURATION HEADWAY      =  2
FLOW IN VEHICLES PER HOUR  =   800      MAXIMUM CAPACITY/CYCLE  =  28

**** SIMULATION RESULTS FROM 85 CYCLES ****

AVERAGE CYCLE LENGTH                =  85.85        S.DEVIATION =  26.65
SIMULATED INTERSECTION V/S RATIO    =  .87          S.DEVIATION =  .16

AVERAGE GREEN TIME    =  41.05        S.DEVIATION =  13.82
AVERAGE RED TIME      =  44.79        S.DEVIATION =  15.25
SIMULATED V/C RATIO   =  .95          S.DEVIATION =  .11

 FLOW/CYCLE........MEAN =  19.84     S.DEVIATION =  8.01     I-RATIO=  3.23
 END OVERFLOW Q....MEAN =  1.52      S.DEVIATION =  3.53     END OF PERIOD= 0
 MAXIMUM QUEUE.....MEAN =  22.05     S.DEVIATION =  9.13
 DELAY/VEHICLE.....MEAN =  29.73     S.DEVIATION =  20.59

 PRESS ANY KEY TO CONTINUE
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FIGURE 2 Sample simulation model output.

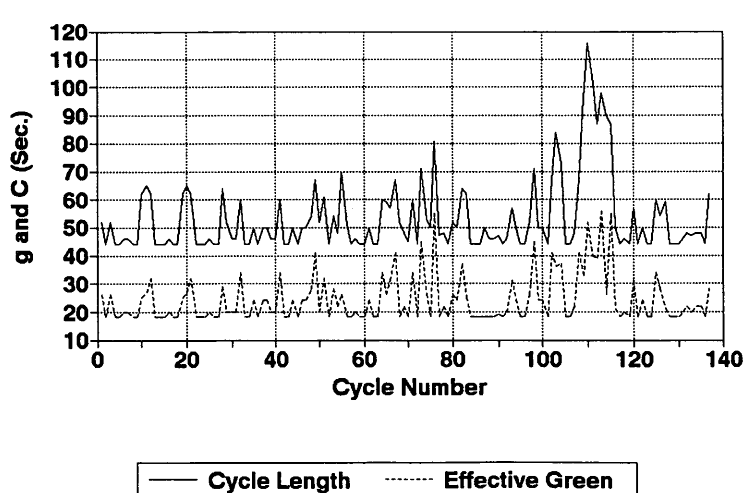

FIGURE 3 Effective green and cycle length for UE = 2.5, average flow rate = 700 vph.

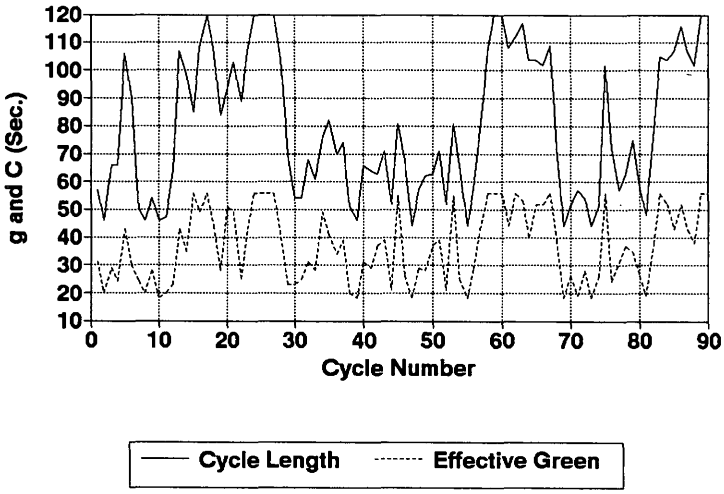

FIGURE 4 Effective green and cycle length for UE = 2.5, average flow rate = 800 vph.

In Figures 5 and 6, the average cycle length obtained from simulation is compared with those estimated from the HCM formula (Equation 4) with X_c = 0.90, 0.95, and 1.0, for unit extensions (UEs) of 2.5 and 4.0 sec, respectively. The minimum and maximum cycles were set at 44 and 120 sec for UE = 2.5 sec and at 60 and 120 sec for UE = 4.0 sec. Compared with the HCM formula, the simulated cycle lengths exhibit a more gradual increase in cycle length with intersection flow ratio. Also noted are the much longer cycle lengths associated with the longer unit extension in Figure 6.

Approach Delays

Simulated delays for a 2.5- and 5.0-sec unit extensions are compared in Figure 7. At low v/c ratios the delays are comparable, except for the effect of the different minimum green (which are higher for UE = 5.0 sec). Had the minimum greens been set equal for the two cases, there would have been no difference in delay. The two delay curves diverge in the region $0.78 < v/c < 0.95$. As v/c approaches 1.0, both curves converge to the maximum settings (and therefore equivalent delays). The results so far have confirmed both expectations and previous results relating delays to unit extensions by Tarnoff (*6*).

Delays were next compared with those estimated from the HCM delay formula for actuated controller [Equation 1, $(d_1 + d_2)$PF where PF = 0.85], using the simulated output values of average cycle, greens, and v/c ratios. The results are depicted in Figures 8 and 9 for unit extensions of 2.5 and 4.0 sec, respectively. The HCM overflow delays were adjusted for a 2-hr analysis period (*20*). The graphs also depict the uniform delay component (Equation 2). The HCM uniform and simulated delays appear to be comparable for v/c up to 0.78 for UE = 2.5 sec (Figure 8) and for v/c up to 0.80 for UE = 4.0 sec (Figure 9). Beyond that value, the HCM formula diverged considerably from the simulated and uniform delays for UE = 2.5 sec but

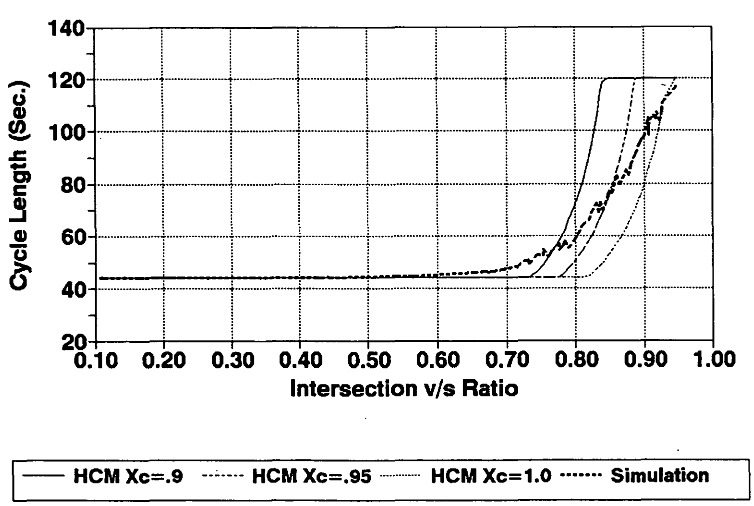

FIGURE 5 Average cycle length: HCM versus simulation for UE = 2.5 sec, L = 8 sec/cycle.

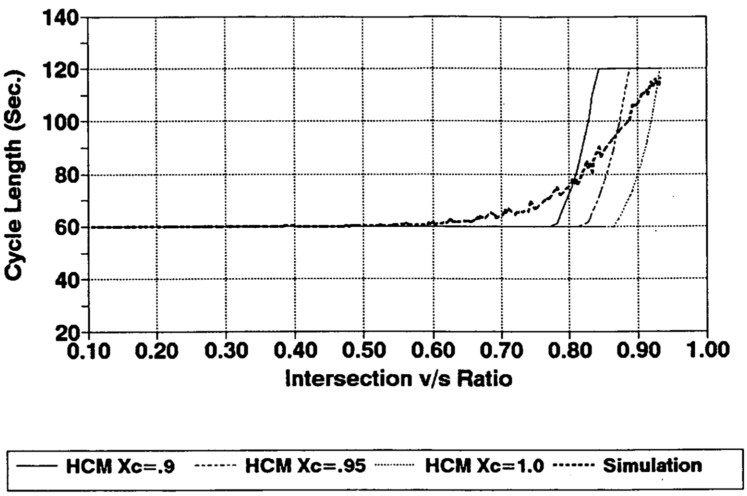

FIGURE 6 Average cycle length: HCM versus simulation for UE = 4.0 sec, *L* = 8 sec/cycle.

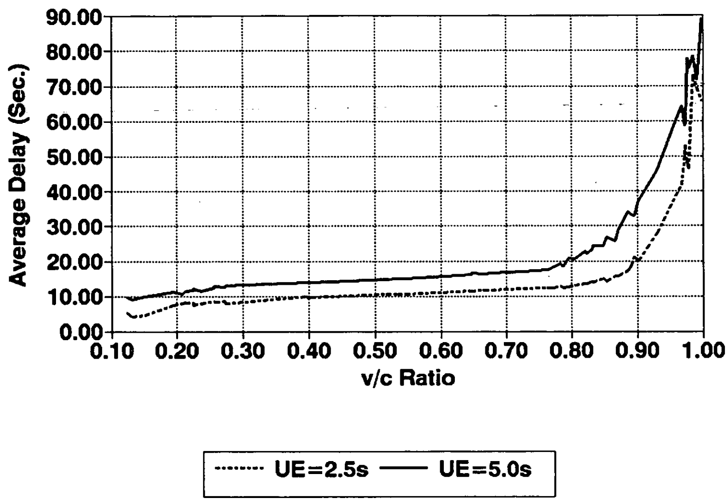

FIGURE 7 Simulated average delay for UE = 2.5 sec versus UE = 5.0 sec.

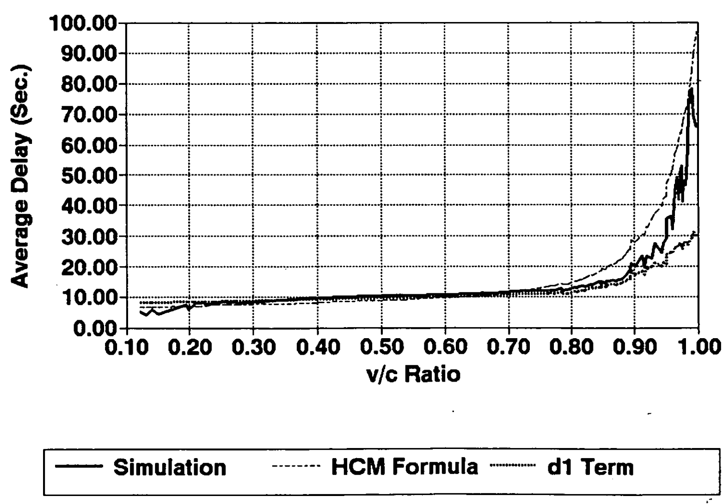

FIGURE 8 Simulated versus HCM delay for UE = 2.5 sec, *L* = 8 sec/cycle.

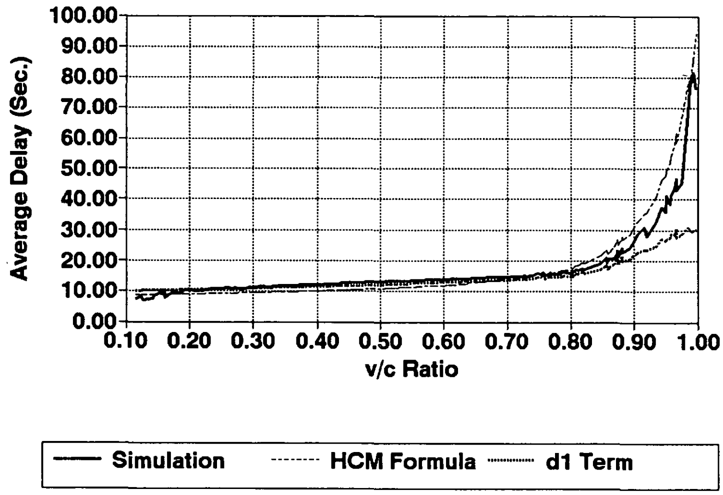

FIGURE 9 Simulated versus HCM delay for UE = 4.0 sec, L = 8 sec/cycle.

only slightly for UE = 4.0 sec. On the other hand, both the simulated and uniform delay curves tracked each other rather well for *v/c* up to 0.90 for UE = 2.5 sec and up to *v/c* = 0.88 for UE = 4.0 sec. The vertical distance between the simulated and uniform delay constitutes the overflow delay value. It is evident from these results that even when supplied with the proper values of average cycle, greens, and *v/c* ratios, the HCM formula tended to overestimate delay compared with the simulated results; the level of overestimation depends on the unit extension setting. In examining Figure 9, it is evident that further increases in the unit extension may actually bring the actuated controller delay close to the HCM delay estimate.

OVERFLOW DELAY MODEL CALIBRATION

Methodology

Referring to the section on delay model framework, the overflow delay model calibration proceeded in two steps. First, the uniform delay term described in Equation 2 was estimated. This requires estimates of the average cycle, green times, and *v/c* ratios. There are three ways of producing these data: first, and preferably, through field observations over a reasonable analysis interval (*19*); second, to derive them analytically using the HCM formula as in Equation 4 or from alternative formulas (*21*); third, to obtain them from a simulation model. Figures 8 and 9 have already indicated that when supplied with simulated values, Equation 2 produced uniform delay estimates that are virtually identical to the simulated delays at low volume conditions (i.e., when the overflow term is actually negligible). Thus, it was decided that Equation 2, using simulated signal timing parameters, is adequate for characterizing the uniform delay term d_1. The overflow delay term was simply estimated as the difference between the simulated approach delay and the computed uniform delay. Because this investigation has so far indicated a strong unit extension effect, separate models were calibrated, one for each unit extension (*22*). All calibrations were performed using the steady-state form of the overflow delay model given by Equation 6. Since only the single parameter k is needed to characterize the model, a simple, no-intercept regression modeling approach was used. Four data sets, each corresponding to a unit extension, were extracted from the simulation. Their characteristics are given in Table 1.

Results

The calibration results for the parameter k along with the overall statistical model evaluation criteria (standard error and R^2) are given in Table 2. The parameter k, which corresponds to pretimed control, calibrated in previous work (*4*) is also presented. It is worth noting that the pretimed steady-state model was also calibrated using the same cycle-by-cycle simulation approach but with fixed signal cycles and splits. The first and most apparent observation is that the pretimed model produced a k-value higher than the actuated models. Second, and as expected, the parameter was found to increase with the size of the unit extension.

TABLE 1 Calibration Data Base Description

Unit Extension(s)	Minimum Cycle(s)	Maximum Cycle(s)	Minimum v/c Ratio	Maximum v/c Ratio	Number of Observations
2.5	44	120	0.131	0.958	78
3.5	54	120	0.126	0.958	123
4.0	60	120	0.116	0.956	144
5.0	70	120	0.104	0.959	159

TABLE 2 Calibration Results for Steady-State Overflow Delay Function

		Traffic Actuated			
		Unit Extension (Second)			
	Pretimed[a]	2.5	3.5	4.0	5.0
Obs.	480	78	123	144	159
k	0.427	0.084	0.119	0.125	0.231
s.e.	NA	0.003	0.002	0.002	0.006
R^2	0.903	0.834	0.909	0.933	0.861
$m = 8k$	3.416	0.672	0.952	1.000	1.848

[a]See Reference (4) for details.

To evaluate the resulting overflow delay model, simple linear regression models were fitted between the predicted (as dependent variable) and simulated (as independent variable) delays for three levels of unit extension, as indicated in Table 3. The first data set, UE = 2.5, did not produce a good fit, with the intercept term significantly higher than 0 and the slope significantly lower than unity. Thus, this model would tend to overestimate delays at low *v/c* ratios and underestimate them at the high *v/c* ratios. On the other hand, the other two data sets produced excellent fits, with intercepts statistically 0 and slopes near unity.

Finally, the derived delay models are compared with the HCM model in the time-dependent form (*12*); they are depicted in Figure 10. Here the HCM formula is expressed by Equation 1; the actuated models apply to UE = 2.5, 3.5, and 5.0 sec and have the general form given by Equation 7. Furthermore, all comparisons are based on an analysis period $T = 0.25$ hr and for a lane group capacity of $Q = 500$ vph. The deterministic oversaturation delay, which applies at very high *v/c* ratios and constitutes the asymptote for all delay models, is also depicted, where

$$d_2 = 1{,}800T(X - 1) \tag{11}$$

It is evident that among all the indicated functions, the one produced by the HCM formula gave the highest overall delays. For the actuated delay functions, the delays were very similar for *v/c* ratios lower than 0.65 and for *v/c* ratios greater than 1.10 (when they all converge to the deterministic model). For values in between, delays were higher for the actuated models with the longer unit extensions.

SUMMARY AND CONCLUSIONS

This paper summarizes a first attempt at developing analytical delay models for traffic under basic actuated signal control using a fixed unit extension (gap time) setting and passage detection. The effort has been guided by what many perceive to be weaknesses in the present HCM methodology with regard to the operational analysis of this type of control. One unanswered question has been the quantification of the effect of actuated control on overflow delay, given that random queues can be better absorbed in an actuated system by virtue of the phase extension feature. Yet the 1985 HCM procedure applies a flat 15 percent delay reduction factor to both delay. Other points of concern include the apparent disconnect between the actuated controller parameters and the resulting signal efficiency, the inability to compare pretimed and actuated control, and methods for estimating the average signal parameters. A nationwide research study aimed at addressing a number of these problems is now under way.

A macroscopic, stochastic simulation model developed in earlier work was adapted for the study of capacity and delays for basic two-phase fully actuated operation. This simulation was previously used in the calibration of a pretimed overflow delay model (*18*). It is capable of modeling and estimating individual cycle lengths, phase times, and delays for up to 400 cycles.

Although the results of the study must be considered preliminary in nature, given the lack of field verification, they nevertheless point to some interesting and consistent trends. As well, many results appear to confirm data and trends found in the literature. To summarize, the following conclusions are offered:

1. The use of a fixed critical X_c ratio in estimating average signal timing parameters for fully actuated operation is not recommended. The appropriate value must be derived from the actual controller settings, such as unit extensions, minimum and maximum greens, and cycles. See the work by Akçelik (*3*), and the preceding paper in this Record) for a detailed derivation of signal parameters.
2. The use of the general overflow delay form given in Equation 7 is recommended. It guarantees convergence to the deterministic oversaturation delay irrespective of the type of control that is implemented. The calibrated models were based on that form.
3. Overflow delay was found to increase with an increase in unit extension, as represented by the parameter m in Equation 7. The increased delay is the consequence of higher cycle lengths and red times, leading to longer queues.
4. Delay differences for various unit extensions in the time-dependent form were not significant for *v/c* ratios lower than 0.65 and for *v/c* ratios greater than 1.10 and were quite close to those experienced under pretimed control. In most cases, the delays at high *v/c* ratios duplicated a pretimed signal at the maximum settings.
5. The calibrated models for actuated control delays yielded lower overflow delay values than the pretimed model. This is a

TABLE 3 Regression Results for Predicted Versus Simulated Delay

Unit Extension(s)	Variable	b_j	$s.e.(b_j)$	T or F	$p > T$ or F	R^2
	Intercept	3.713	0.456	8.133	0.0001	
2.5	Slope	0.830	0.018	86.453[a]	0.0001	0.965
	Intercept	0.065	0.577	0.133	0.9106	
3.5	Slope	1.076	0.027	8.211[a]	0.0053	0.951
	Intercept	0.298	0.696	0.428	0.6695	
5.0	Slope	1.036	0.029	1.465[a]	0.2286	0.909

[a] Test for Slope = 1 (F test).

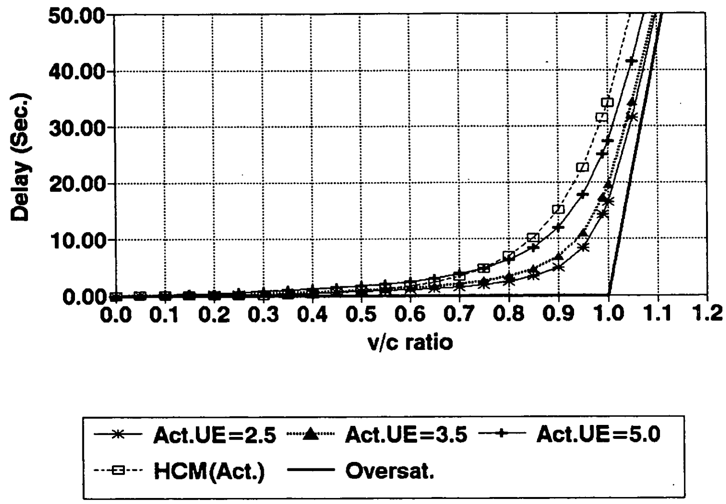

FIGURE 10 Overflow delay comparison time-dependent form, $T = 0.25$ hr, $Q = 500$ vph.

result of the actuated controller's ability to operate high *v/c* ratios without incurring substantial random queues and delays.

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