Enhancements to the PASSER II-90 Delay Estimation Procedures

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An enhanced delay estimation model for the popular traffic signal optimization model PASSER II-90 is described. Although the results from this model focus on enhancements to PASSER II-90, the findings presented should be useful to the future formulation of the *Highway Capacity Manual* (HCM) methodology for arterial streets. Development of the enhanced delay model primarily involved a four-step arrival rate model instead of the current two-step arrival rate model. Total delay was calculated on the basis of whether the traffic arrivals were early or late. Specifically, delay was estimated using the length and the time of arrival of the traffic platoon at the downstream intersection. TRANSYT-7F was used to investigate the effectiveness of the current PASSER II model and the enhanced PASSER II model. The enhanced PASSER II delay model resulted in large reductions in deviations of the delay values from TRANSYT-7F. Delay-offset trends in enhanced PASSER II-90 now closely follow the TRANSYT-7F delay-offset curves. Delays were also observed to closely follow the NETSIM curves in some regions. It was also observed that in the optimization mode, there was no significant difference in the calculated delay values between the old and the new estimation models. The new delay estimation model in PASSER II-90 also demonstrated that the platoon dispersion modeling in PASSER II compares favorably with TRANSYT's platoon dispersion factor of 0.30 to 0.35. Conclusively, the new model in PASSER II-90 has substantially improved delay estimation over all possible offsets for through traffic.

Delay analysis of signalized coordinated intersections is a very intricate process that requires a thorough understanding of the complex interactions among traffic demand, signal timing parameters, and traffic behavior. Chapter 9 of the 1985 *Highway Capacity Manual* (HCM) (*1*) devotes considerable space to the analysis of signalized intersections. The HCM uses average stopped delay per vehicle as the sole criterion for defining the levels of service provided at signalized intersections. One of the more important operational factors in determining the level of service at signalized intersections is the quality of traffic progression. Of all the variables affecting delay, the quality of traffic signal progression has the largest potential impact as shown by the wide range of progression adjustment factors (PFs), 0.4 to 1.85, in Table 9-13 of the HCM. Of concern to traffic engineers, however, is the fact that the PFs are based on limited field data. Hence, selection from a reasonable range of PFs in the table may often result in changes in the level-of-service designation for the approach (*2*).

Because of these concerns and because of the complexity involved in estimating and optimizing several signal-timing parameters, several computer simulation models have been developed by researchers for optimizing signal timing for signalized coordinated arterial streets and for networks. Familiar models to traffic engineers among these are TRANSYT-7F (*3*), MAXBAND (*4*), and PASSER II (*5*).

Despite the fact that TRANSYT-7F and its traffic model are realistic, it produces signal timing parameters that attempt to minimize disutility functions such as delay, stops, fuel consumption, and so on. But in reality, a major consideration in designing traffic signal timings for arterials (i.e., a series of intersections) is to achieve a reasonable amount of progression so that drivers who are traveling in the progression band are not required to stop at subsequent intersections once they have cleared the first intersection in green. TRANSYT-7F, thus, may not the best model for the traffic engineer to use where progression is the main consideration.

MAXBAND produces signal settings that achieve good progression but cannot guarantee delay minimization. Hence, results generated by MAXBAND may be efficient at providing large bands, but at the same time may cause undesirable systemwide delays. This deficiency in MAXBAND narrows its range of applications.

A model that overcomes these deficiencies to some extent is the PASSER II-90 program. PASSER II-90 is a macroscopic, deterministic model designed to optimize signal timing parameters to provide good progression along arterial streets. When the model was first developed in 1974, the sole purpose was to provide progression for the arterial through traffic. In 1978, delay evaluation for the progression solution was incorporated into the program. The model was further enhanced in 1987 by building simulation output into the program. Although the delay model in PASSER II-87 was better than that adopted by the 1985 HCM, it still had some inherent deficiencies in that the model did not take into account early or late traffic arrivals. Hence, the present paper focuses on more appropriate calculations of delay in the PASSER II program.

The main objectives of this paper are (*a*) to analyze the effectiveness of the traffic model and delay estimation for early or late traffic arrivals in PASSER II-90; (*b*) to demonstrate enhancements to the platoon dispersion or delay estimation models, or both, in PASSER II-90; and (*c*) to recommend analytical equations that are useful to the future HCM methodology for calculating delay to progressed movements at signalized intersections.

BACKGROUND

In the following sections, techniques adopted by the 1985 HCM and other models in estimating delay are elucidated.

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HCM Methodology (1985)

The HCM uses average stopped delay per vehicle for defining levels of service at signalized intersections. Stopped delay is estimated in the HCM using the following equations:

$$d = d_1 + d_2 \quad (1)$$

$$d_1 = \frac{0.38 * C * (1 - g/C)^2}{[1 - (g/C) * X]} \quad (2)$$

$$d_2 = 173X^2 * [(X - 1) + \sqrt{(X - 1)^2 + 16X/c}] \quad (3)$$

where

- d = average stopped delay per vehicle (sec/veh),
- d_1 = first-term delay for uniform arrivals (sec/veh),
- d_2 = second-term delay for incremental random and overflow effects (sec/veh),
- C = cycle length (sec),
- g = effective green time (sec),
- c = signal capacity (veh/hr), and
- X = ratio of demand volume to signal capacity (v/c).

The HCM accounts for the effects of progression (platoon and dispersion effects) through the use of some adjustment factors called progression adjustment factors (PFs). The delay term d in Equation 1 is multiplied by the appropriate PF to obtain the actual average stopped delay. This PF is obtained from Table 9-13 of the HCM and depends on the v/c ratio and arrival type of the approach traffic. Five arrival types are used based on a variable called the platoon ratio, which is defined as the ratio of the percent vehicles arriving on green (PVG) to the green ratio of the movement. Platoon ratios (R_p) may range from a minimum value of 0 to a value greater than or equal to 1.5. Qualitatively, increasing platoon ratios or increasing arrival type numbers signify increasing progression.

Proposed Enhancements to HCM Methodology

A recent study (*2*) has suggested that applying the PF to the incremental delay term (Equation 3) is not appropriate. This argument seems logical because progression effects become negligible when oversaturated conditions exist, and hence the second term of the delay equation should not contain any external adjustment factors for platoon traffic.

Further, as has been pointed out by several researchers (*2,6*), the R_p and PF used by HCM are dependent on the g/C ratio of the approach. Since the quality of progression is a function of several variables such as signal offset, spacing between the intersections, dispersion, and traffic volume, the platoon ratio may not be an accurate descriptor of the quality of signal progression. The PFs thus derived from the corresponding R_p-values may not best determine the delay values. In addition, no consideration is given to the early or late traffic arrivals by the PFs.

Fambro et al. (*2*) developed a new set of PFs to be used as replacements for Table 9-13 of the HCM. The existing delay equation was modified to include a term for the quality of signal progression. A set of empirical factors was also proposed to take into account early and late traffic arrivals at successive intersections. Those factors were derived on the basis of whether the front of the platoon arrived during the first, middle, or last third of the green or red periods. The equation and the adjustment factors may eliminate some of the existing discrepancies in the current method of HCM delay estimation. In PASSER II, however, more detailed knowledge of dispersion, offset, and other variables may be used to more accurately predict the delay without using empirical adjustment factors.

Other Delay Formulations

Rouphail (*7*) derived several delay formulations for mixed platoon and secondary flows. One model assumes two arrival flow rates, one within the progression band and another outside the progression band. Though the model seems better than most existing models, it effectively disregards the early or late traffic arrivals at the downstream intersection. When traffic arrivals vary or straddle the green, there are, in effect, three arrival rates. The method also requires bandwidth as an input.

In addition to the delay equation proposed by Fambro et al. in National Cooperative Highway Research Program (NCHRP) Report 339, which includes a term for the quality of signal progression, Staniewicz and Levinson (*8*) developed several equations for various arrival types. These equations, however, may not be used for secondary flow conditions. They are also more microscopic in nature and thus are not practical to incorporate into PASSER II-90.

TRANSYT Methodology

TRANSYT (*9*) has become one of the most widely used tools for traffic flow analysis and traffic signal timing optimization in the world. The effectiveness of the signal timings developed by the program depends heavily on the delay calculated by the model. The delay calculation in TRANSYT for coordinated signalized intersections is estimated by integrating the arrival and departure profiles of traffic at the downstream intersection. The accuracy of the arrival flow profile at the downstream intersection in turn depends on the platoon dispersion algorithm utilized by TRANSYT. Thus, the fundamental principle of traffic representation in TRANSYT is the platoon dispersion behavior. TRANSYT uses a recursive formula to predict the platoon dispersion behavior of the traffic. Further discussion on platoon dispersion modeling in TRANSYT may be found in the User's Manual (*3*).

MODEL DEVELOPMENT

Three major stages were involved in developing the model together with analyzing and evaluating the methods of traffic delay modeling in PASSER II. First, an arbitrary arterial street system was established with all the traffic and signal timing variables affecting the delay estimation well defined.

Second, a factual method of examining the accuracy of the traffic modeling or delay estimation procedures was adopted. This analysis was intended to determine if the delay estimation procedures indeed showed some inconsistencies and modifications were in order. This determination was achieved by observing delay-offset relationships in PASSER II-90 against those in TRANSYT-7F.

The third stage involved developing enhancements to the existing modeling procedures in PASSER II. On the basis of results from the second stage, new or enhanced modeling techniques that would have significant impact on the output were devised.

Stage 1: Establishment of Arterial Street System

A two-intersection arterial was defined for the purposes of this research. The traffic modeling or delay estimation methods (hereafter referred to as the TRAMDE methods) and the trends of results in PASSER II would be the same irrespective of the number of intersections in the arterial. Though the study on the response of PASSER II to different traffic and signal settings was made with varying spacings, the principal focus was on a spacing of 403 m, which was deemed to be a reasonable and ideal representation of platoon dispersion along an arterial system.

The signal timing parameters that were needed for the simulation were cycle lengths, phase splits, offsets, and so forth. A cycle length of 100 sec was chosen for convenience, with green splits of 40 and 60 percent for progressed and nonprogressed traffic flow, respectively. The choices were based on the fact that main street green splits for multiphase signals are generally not more than 50 percent of the cycle length. Offsets were varied from zero to the cycle length in multiples of 5 sec.

Traffic volumes were such that the intersections always remained undersaturated, since quality of progression has an insignificant effect on the uniform delay component for oversaturated conditions. A *v/c* ratio of 0.5 or 0.8 was considered to be reasonable to represent moderate and high-volume conditions, respectively.

Two cases of volume variations were examined. The first variation excluded any secondary flow component from the upstream intersection to the downstream intersection. The second variation was to assign 20 percent of the through volume at the downstream intersection to the nonprogressed traffic at the upstream intersection. This variation was done to examine the appropriateness on the part of the program in modeling the secondary flow.

Stage 2: Identification of Procedures for Investigating TRAMDE Methods in PASSER II

As has been pointed out in earlier sections, a widely accepted program for traffic model and delay estimation is TRANSYT-7F. Though there are some conflicting views on an appropriate platoon dispersion factor for TRANSYT, the recommended value of 0.35 seems a plausible value that represents fairly good traffic conditions in the field in most cases. The delay estimates of TRANSYT-7F have proved to be reliable throughout the world. Hence, TRANSYT-7F was chosen for examining the proposed delay estimation enhancements in PASSER II.

Delay-Offset Relationships

A logical way to study the delay estimation method was to examine whether the delay-offset trends in PASSER II and TRANSYT were similar for various intersection spacings and traffic volumes. In order to verify accurate trends, an established microscopic simulation program, NETSIM (*10*), was used to corroborate the findings. Various combinations of inputs that were tested for this analysis were (*a*) two main street volume variations with *v/c* ratios of 0.48 and 0.8, respectively; (*b*) a spacing of 403 and 805 m; (*c*) offset variations ranging from 0 to the cycle length in 5-sec increments; and (*d*) a platoon dispersion factor (α) of 0.35. Several values of α would make the analysis too complicated for the anticipated benefits. Hence, an α-value of 0.35 was used.

Figure 1 shows the delay-offset curves for 0 percent non-progressed volume and a *v/c* ratio of 0.48 for progressed traffic at a spacing of 403 m for PASSER II-90, TRANSYT-7F, and NETSIM. Figure 2 shows a similar curve for the same parameters with a *v/c* ratio of 0.8. The plots clearly show an inconsistency of shapes on the part of PASSER II-90 in estimating delay in some offset regions.

In both of the above cases, it can be clearly seen that the delay in PASSER II was either overestimated or underestimated in two or more regions. Figures 1 and 2 reveal that PASSER II consistently overestimates the delay on the right side of the ideal offset and underestimates the delay on the left side of the curves. The portion of the curves on the right side of the ideal offset signifies early traffic arrivals, where the front of the traffic platoon arrives in the later part of the red period. Increasing offsets to the right of the ideal offset indicate that the green time to the platoon traffic is being displayed late, and hence traffic arrivals automatically become early. On the other hand, the portion of the curves to the left of the ideal offset indicates late arrivals, where the rear of the platoon arrives in the early portion of the red. This inconsistency was largely due to the delay estimation in the red period for early and late traffic arrivals made by PASSER II.

This flaw in the delay estimation necessitates a thorough understanding of the traffic and delay modeling techniques currently used in PASSER II-90. These techniques of PASSER II will be detailed in the following section.

Traffic and Delay Modeling in PASSER II

A major component of traffic representation in any macroscopic model for signalized intersections is the platoon dispersion model. The model in PASSER II (*11*) uses platoon length at the upstream intersection to estimate platoon length at the downstream intersection. The length of the platoon at the upstream intersection i, LP_i, is given by

$$LP_i = g_o[PVR + (PVG * g_o)/g] + PVG(g - g_o) \quad (4)$$

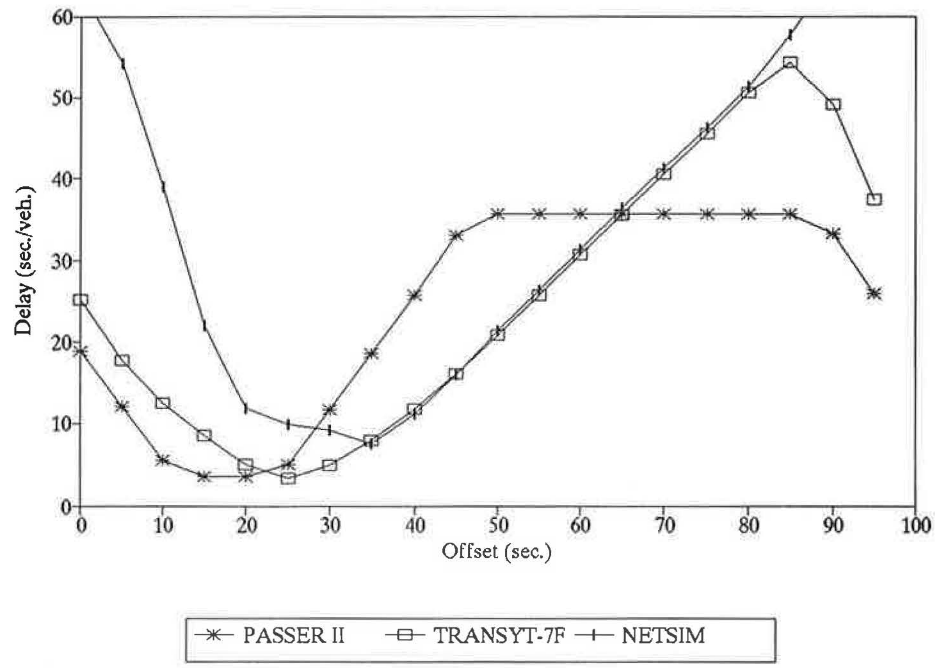

FIGURE 1 Delay-offset relationships for *v/c* = 0.48 and spacing = 403 m (100 percent platoon traffic; alpha = 0.35, φ = 26.4).

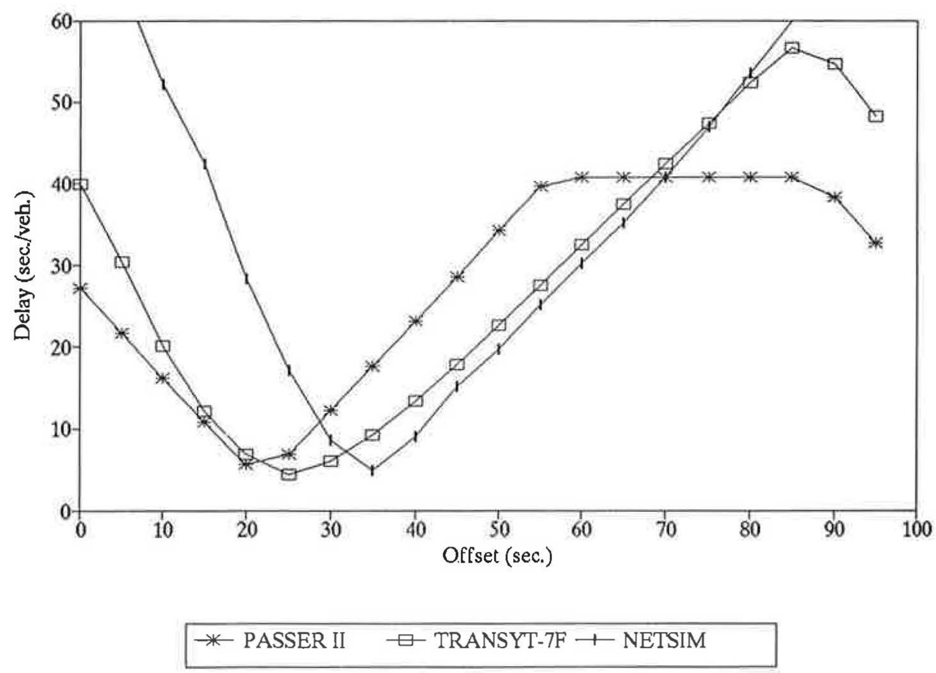

FIGURE 2 Delay-offset relationships for *v/c* = 0.8 and spacing = 403 m (100 percent platoon traffic; alpha = 0.35, φ = 26.4).

where

g_o = time required for queued vehicles to clear the intersection at i (sec),
PVR = percent vehicles arriving on red at i,
PVG = percent vehicles arriving on green at i, and
g = effective green time for the main street at i (sec).

The platoon length at the downstream intersection (j), LP_j (see Figure 3) is now estimated as

$$LP_j = LP_i * PD_{ij} + 0.8(0.9 + 0.056t_{ij}) \quad (5)$$

where

PD_{ij} = platoon dispersion factor written as in the report by Messer et al. (*5*),
= $1.0 + (0.026 - 0.0014 * NP)\, t_{ij}$, in which t_{ij} = travel time between i and j in seconds and NP = number of vehicles in platoon at i.

The percent vehicles arriving on green (PVG) is a critical factor in the delay calculation. PASSER II-90 estimates PVG using the following formula:

$$PVG = PTT_j * GO_j/LP_j + (1 - PTT_j)RO_j/(C - LP_j) \quad (6)$$

where

PTT_j = percent of total through traffic arriving from i at j,
= (through traffic at i/through traffic at j),
GO_j = green overlap for the through traffic from i at j as shown in Figure 3 (sec), and
RO_j = green overlap for the secondary flow component from i at j (sec).

The flow rate in the green period (q_g) is calculated by the relation

$$q_g = PVG * q * C/g \quad (7)$$

The percent vehicles and the flow rate in the red period at j are calculated using the following relation:

$$PVR = 1 - PVG$$

$$q_r = PVR * q * C/r \quad (8)$$

where

q = average flow rate of through traffic at j (veh/sec),
C = cycle length (sec),
g = effective green (sec),
PVR = percent vehicles in red at j, and
r = effective red (sec).

Figure 4 shows how PASSER II defines these two flow rates, q_g and q_r, in the cycle at j. This definition was also proposed by Olszewski (*6*). These are the two flow rates that PASSER II uses to calculate the uniform delay component of the average delay. The uniform delay is now computed using a stepwise integration of the queue lengths in the red and green periods. An approximation of the uniform delay (UD) calculation, in seconds per vehicle, can be written in the following form:

$$UD = q_r * r^2 / (2 * q * C)[1 + q_r/(s - q_g)] \quad (9)$$

where s is the saturation flow rate in vehicles per second per green per lane and all other terms are as explained before.

A deeper look at Equation 6 would suggest that for a given C, g, r, and platoon volumes, PVG and hence PVR would always yield the same value if GO_j and RO_j are constant. Under these conditions, q_r would always be the same irrespective of the time at which the platoon arrives in the red period. Consequently, the obtained UD would be the same and the delays experienced by traffic arrivals in the early part of the red (late arrivals) and later part of the red (early arrivals) are also the same when in reality they are considerably different. In the former case (late arrivals), delay is much

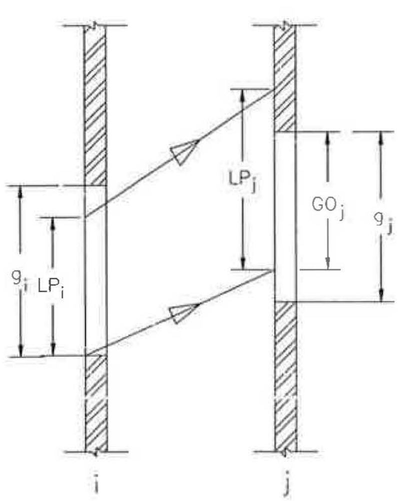

FIGURE 3 Model of progression platoon movement from intersection *i* to *j* used by PASSER II-90.

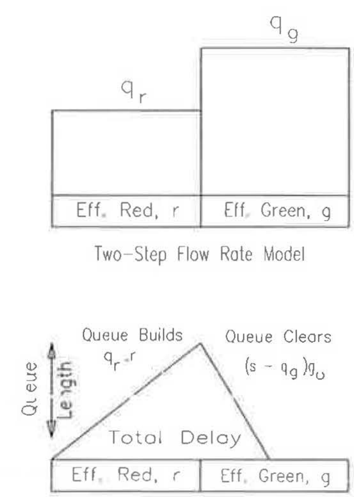

FIGURE 4 Flow-rate definition and delay calculation in PASSER II (*11*).

higher than in the latter case (early arrivals). It can also be observed that the flow rate for the platoon and secondary flows is combined into one flow rate in both green and red periods, which may not invariably be true. A major deficiency of PASSER II lies in these flow rate definitions and subsequent delay computation methods. Enhancements in these two techniques will be dealt with in the next section.

Stage 3: Enhancements to Existing Model

Two enhancements were made to the existing model; the major enhancement was the delay estimation technique in PASSER II.

First Enhancement

The first modification was concerned with the platoon dispersion aspect of PASSER II and was developed for easy comprehension. An equivalent form of Equation 4 can be written as

$$LP_i = g_o + PVG(g - g_o)^2/g \quad (10)$$

where all the terms are as previously defined.

Though Equation 10 was developed analytically, the same equation can also be derived by mathematical manipulation of Equation 4. Equation 10 is simplistic, easy to understand, and also easy to incorporate into the program. Further, the boundary conditions of Equation 10 are easily discernible, unlike those of Equation 4. For example, when $PVG = 0$, LP_i is equal to g_o, and when $g_o = g$, $LP_i = g$. From a glance at Equation 10, one can easily determine these boundary conditions, whereas Equation 4 requires some computation to arrive at the same boundary conditions.

Second Enhancement

Major modification in PASSER II-90 involved the delay calculation made by PASSER II for the vehicles arriving in the red period. Figure 5 shows the proposed modification made for PASSER II for the estimation of q_r. The modification involves defining three arrival rates in the red period at the downstream intersection: a flow rate for the early traffic arrivals, which are part of the main street platoon traffic; a flow rate for the late arrivals, also part of the main street platoon traffic; and a flow rate for the nonprogressed traffic during the red. The flow rates were calculated using the following equations:

$$q_{re} = PTT_j * r_e/LP_j$$

$$q_{rl} = PTT_j * r_l/LP_j$$

$$q_{\text{rel}} = (1 - PTT_j) * [r - (r_e + r_l)]/(C - LP_j)$$

where all the variables are as defined earlier except

q_{re} = flow rate for the early arrivals of the platoon traffic,
q_{rl} = flow rate for the late arrivals of the platoon traffic,
q_{rel} = flow rate (early/late) for the nonplatoon traffic,
r_e = red overlap for the early platoon traffic (Figure 5), and
r_l = red overlap for the late platoon traffic (Figure 5).

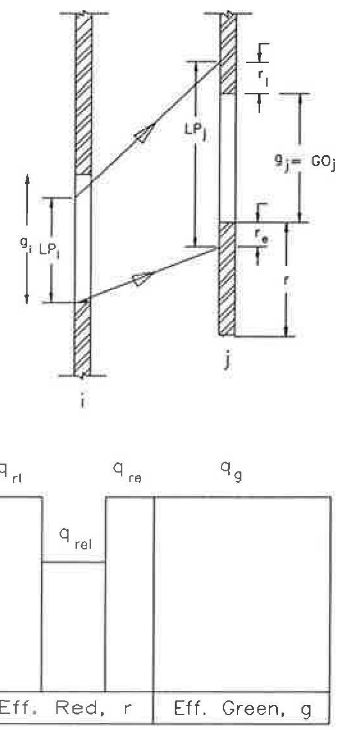

FIGURE 5 Modified flow-rate definitions in PASSER II.

The flow rates q_{re} and q_{rl} will be equal because of the assumption of a constant flow rate in the platoon length LP_j as shown by Equation 6. The nonplatoon flow rate will be late whenever the platoon flow rate is early or straddles the red. Similarly, q_{rel} will be early whenever the platoon traffic is late. When the front and rear of the platoon traffic arrive in the red period, q_{rel} will be both early and late with equal flow rates as for the platoon traffic. The uniform delay (UD) estimation was then made in the program using the same stepwise demand integration with only minor modifications.

An approximate equation similar to the HCM equation for the foregoing estimation in most cases was derived in two parts. The first part (UD1) was meant for the platoon traffic delay in the red, and the second part (UD2) was meant for the nonplatoon traffic. The first part is given below:

$$UD1 = [q_r * r^2/(2 * q * C)] * \text{FEAL} \quad (11)$$

where

q_r = platoon flow rate in the red, q_{rp};
= $(PTT_j - PVG_{jp}) * q * C/r$ (veh/sec);
PVG_{jp} = percent vehicles in green for the platoon traffic;
= $(PTT_j * GO_j/LP_j)$; and
FEAL = factor for early and/or late arrivals as given by $[(r_e - r_l)/r] + [2 * r_l/(r_l + r_e)]$.

All other variables have been defined previously. Note that Equation 11 is similar to the uniform delay equation in the red part as proposed by Fambro et al. in NCHRP Report 339 with just one additional analytical factor to explicitly take early and/or late traffic arrivals into account.

The second part of the uniform delay term for the nonplatoon traffic (UD2) is the same as Equation 11 except that r_l and r_e have different values for the secondary flow. Also, q_r, nonplatoon flow rate in the red, will be different. It is estimated in vehicles per second as

$$q_r = (1 - PTT_j) - PVG_{np} * q * C/r$$

where PVG_{np}, percent vehicles in the green for the nonplatoon traffic, is $(1 - PTT_j) * RO_j/(C - LP_j)$.

The final approximate uniform delay term is

$$UD = UD1 + UD2 + q_r^2 * r^2/(2 * q * C)[1/(s - q_g)] \quad (12)$$

where q_r is the value obtained from Equation 8.

It can be noted that the delay during the queue clearance time at the downstream intersection is not affected by the early and/or late platoon or nonplatoon arrivals, which is logically true. Equation 12 is similar to the equation in NCHRP Report 339 with arrival rates for platoon and nonplatoon traffic distinctly computed. The NCHRP Report 339 equation for uniform delay is given as

$$UD = [q_r * r^2/(2 * q * C)] * [1 + q_r/(s - q_g)] \quad (13)$$

MODEL RESULTS

Delay-Offset Relationships

The delay-offset relationships were further examined with respect to the modified equations in PASSER II-90. Plots of the results are shown in Figures 6–8.

Figure 6 shows the delay-offset relationships for 0 percent nonprogressed traffic and a v/c ratio of 0.48. Figure 7 presents a delay-offset plot for a v/c ratio split of 0.67:0.17 between the platoon and the nonplatoon traffic, respectively, at the upstream intersection. This split represents a nonprogressed traffic v/c ratio at the upstream intersection that is 20 percent of the total approach v/c ratio (approximately 16 percent nonplatoon flow). The spacing between the intersections in both cases was 403 m. To add generality, Figure 8 shows the delay-offset curve for a 30 percent nonplatoon flow at a spacing of 201 m. Note that all the TRANSYT-7F plots were calculated with a platoon dispersion factor of 0.35 (α = 0.35).

The graphs clearly show a significant improvement in delay estimation by the PASSER II-90 model. The delay-offset trend clearly traces the TRANSYT curve in virtually all cases. Table 1 summarizes the average and the maximum percent deviation of the old PASSER II-90 delay estimation (similar to Equation 13) and the new PASSER II-90 delay estimation (similar to Equation 12).

The average percent deviation in Table 1 is the percent deviation of all the delay values averaged from a 0-sec offset to a 95-sec offset. The maximum percent deviation of delay between the old and new PASSER II from TRANSYT is also given in the table.

Simulation Versus Optimization Results

The modified delay estimation technique was also tested with two optimization runs for an arterial consisting of four intersections. The maximum percent deviation obtained for the through traffic movement was 47 percent with the optimization run. There was no significant difference between the old and the new delay values as far as the absolute differences were concerned. The maximum absolute difference between

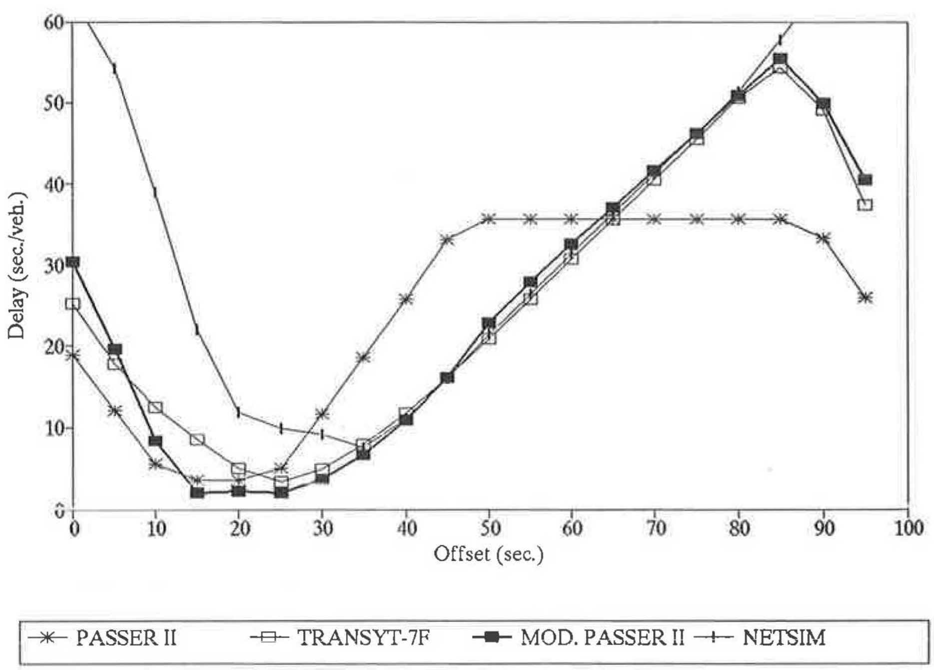

FIGURE 6 Modified delay-offset relationships for v/c = 0.48 and spacing = 403 m (100 percent platoon traffic; alpha = 0.35, ϕ = 26.4).

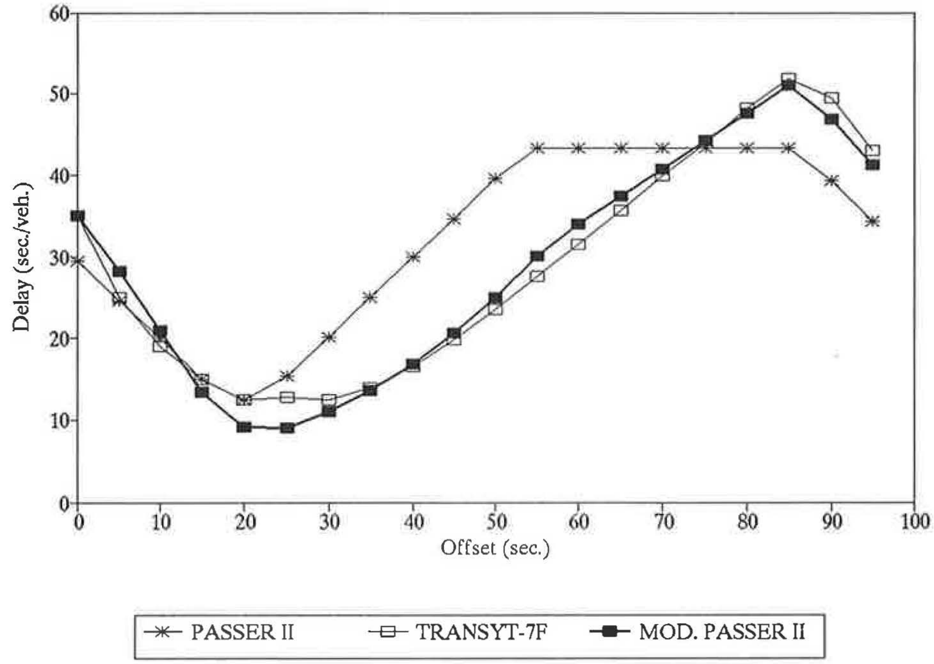

FIGURE 7 Modified delay-offset relationships for *v/c* = 0.8 and spacing = 403 m (16 percent nonplatoon traffic; alpha = 0.35, ϕ = 26.4).

the old and new PASSER II delay estimates was observed as 4 sec in the optimization runs. This negligible difference between the old and the new delay estimates can be attributed to the fact that with optimization, the model attempts to maximize through traffic arrivals and departures in the green time, thus minimizing early or late traffic arrivals in the red period. In addition, observations of Figure 1 show that small differences in delay between PASSER II-90 and TRANSYT-7F occur near optimal progression delays.

CONCLUSIONS AND RECOMMENDATIONS

Summary

An enhanced delay estimation model for the popular traffic signal optimization model PASSER II-90 has been provided. The enhanced delay estimation model primarily involved development of a four-step arrival rate model instead of the current two-step arrival rate model. Total delay was calculated

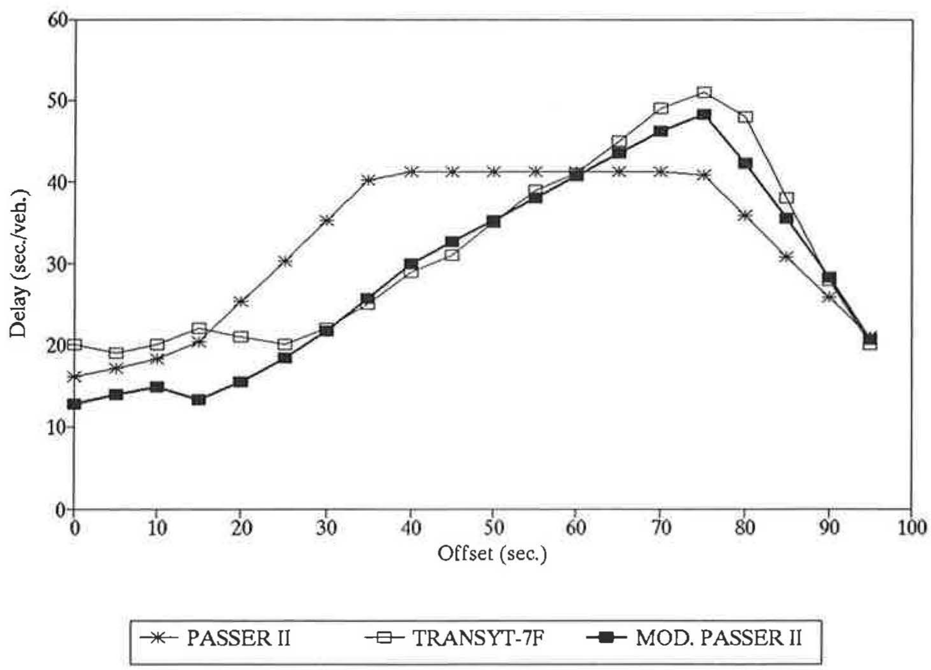

FIGURE 8 Modified delay-offset relationships for *v/c* = 0.8 and spacing = 201 m (30 percent nonplatoon traffic; alpha = 0.35, ϕ = 13.2).

TABLE 1 Deviations of Old and New PASSER II-90 from TRANSYT-7F

	Deviations (%)			
	Average		Maximum	
Case	Old	New	Old	New
v/c = 0.48 100% platoon s = 403 meters	50.2	16.4	140	76
v/c = 0.8 100% platoon s = 403 meters	37.6	8.2	103	32
v/c= 0.8 16% non-platoon s = 403 meters	25	11.8	53	42
v/c = 0.8 30% non-platoon s = 201 meters	21.9	10.9	61	40

on the basis of early or late traffic arrivals. In other words, delay was estimated using the length and the time of arrival of the traffic platoon at the downstream intersection.

TRANSYT-7F was assumed as a model that could predict accurate delay values and was used to investigate the effectiveness of the current PASSER II model and the enhanced PASSER II model. In some cases, NETSIM was also used as a check for consistency in delay estimation.

Conclusions

The enhanced PASSER II-90 delay model resulted in large reductions in percent deviations of the delay values from TRANSYT-7F. Delay-offset trends in PASSER II-90 were observed to closely follow the TRANSYT-7F delay-offset curves. Delays were also observed to closely follow the NETSIM curves in the portion to the right of the target offset. NETSIM predicted much higher delay values in the region where the offset was lower than the target offset in the delay-offset curves. It is possible that this disparity occurred because NETSIM was estimating too many late traffic arrivals.

The enhanced delay estimation technique was also examined with respect to signal optimization in PASSER II-90. It was observed that there was no significant difference in the calculated delay values between the old and the new estimation models. The maximum absolute difference was observed to be about 4 sec, and in terms of deviation from TRANSYT-7F, it was 47 percent. This negligible difference between the old PASSER II-90 delay modeling and the new delay modeling in PASSER II-90 was mainly because most of the through traffic platoon was arriving and leaving in the green time, and hence there were few early or late traffic arrivals.

The new delay estimation model in PASSER II-90 also demonstrated that the platoon dispersion modeling in PASSER II compares with TRANSYT's platoon dispersion factor of 0.30 to 0.35 (as indicated by the delay-offset curves). Hence, it can be stated that PASSER II's platoon dispersion model may not need refinements or enhancements. Conclusively, the new model in PASSER II-90 has substantially improved the delay estimation for the through traffic.

Recommendations to NCHRP Report 339 Equation

As discussed earlier, Fambro et al. (*2*) proposed modifications to the HCM methodology for calculating uniform delay. Progression adjustment factors were proposed to take early or late traffic arrivals into account. As a modification to these empirical factors, an analytical factor (FEAL) is recommended as given in Equation 11. Uniform delay is divided into three parts as given in Equation 12. The first two parts take into account the delay in the red period for primary and secondary flows and the third part calculates delay during the clearance time.

Estimation of all variables in Equation 12 was described in earlier sections. A discussion on measuring delay in the field may be found in NCHRP Report 339 (Chapter 1, p. 15). Note that to apply Equation 12, two additional steps are required:

1. Isolate measurement of the proportion of volume arriving on the green for the primary traffic from the total proportion of volume arriving on the green, and
2. Measure the time of arrival of the front and/or rear of the primary platoon traffic with respect to the start of green.

Once these steps have been completed, Equation 12 can be applied. It is hoped that Equation 12 in conjunction with the NCHRP Report 339 equation will yield reliable uniform delay estimates for application in Chapters 9 and 11 of the HCM.

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