

SIGNALIZED INTERSECTION DELAY ESTIMATION: CASE STUDY COMPARISON OF TRANSYT-7F, SYNCHRO, AND HCS

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ABSTRACT

Performing signal timing analyses for a series or network of coordinated signals is a complicated task. This type of analysis has only been practical since the development of specialized software applications for the task. For years, TRANSYT-7F has been the industry standard for performing this task. Due to the general complexity of input file coding for this program, some other programs with more “user friendly” input editors have started to increase in popularity. At this point, one of the most popular alternatives to TRANSYT-7F is the program named Synchro. Despite the popularity of both programs, comparisons between the two have been generally lacking. The primary focus of this paper was to compare the signal delay estimates reported by TRANSYT-7F and Synchro with those given by the Highway Capacity Software (HCS). The paper also provides some background on the analysis methodologies used in these three programs. Applying the software packages to a signalized arterial case study in the Seattle, Washington area, facilitated the comparisons in this paper.

INTRODUCTION

The determination of delay at signalized intersections is a relatively complicated task. With each subsequent release of the Highway Capacity Manual (HCM) (1), the procedures generally get more accurate, but also more complex. Consequently, transportation engineers typically rely on software implementations of the HCM procedures to perform signalized intersection analyses. The use of software packages has also enabled transportation engineers to perform much more complex analyses, such as signal coordination, with relative ease. Although computer software usually reduces the time and effort to perform an analysis, it also distances the user from the underlying analysis principles or methodologies that determine the results.

The accepted standard for isolated signalized intersection analysis is the 1997 HCM, specifically chapter 9. Many software implementations of this chapter have been produced, but the most commonly used is the Highway Capacity Software (HCS) (2). Since chapter 9 of the HCM is really geared towards individual intersection analysis and does not provide for explicit modeling of coordinated intersections, other software packages have been developed for this purpose. For years, TRANSYT-7F (3) has been the industry standard for performing this task. Due to the general complexity of input file coding for this program, some other programs with more “user friendly” input editors have started to increase in popularity. At this point, one of the most popular alternatives to TRANSYT-7F is the program named Synchro (4). Although software packages such as TRANSYT-7F and Synchro are the preferred packages by transportation engineers for analyzing a coordinated series of signals, many public agencies stipulate the HCM/HCS as the standard for reporting intersection delays and the corresponding levels of service. Therefore, unless a software program designed for modeling a system of signals also reports delay in a manner consistent with the HCM, the user must either also perform individual intersection analyses in HCS or estimate arrival types for the coordinated conditions and perform just the isolated intersection analyses in HCS to conform to the public agency requirements. To many transportation engineers, this would be perceived as a duplication of effort. Therefore, most, if not all, users would prefer to use just a single software package like TRANSYT-7F or Synchro for coordinated signal arterial analysis and use the individual intersection delay estimates from these packages for reporting to public agencies as part of traffic impact studies. Thus, a common question among the practicing profession pertains to how closely the signal delay estimates given by TRANSYT-7F and Synchro compare with those given by the HCS.

This paper has two purposes: 1) to provide the reader some background on the analysis methodologies used in the three programs discussed in this paper and, 2) to compare the primary measure of signalized intersection performance, control delay, reported by the three software packages. The comparisons in this paper were facilitated by application of the programs to the same set of conditions—a coordinated signalized arterial in the University District of Seattle, Washington, as well as previous author experience with the programs. This paper also discusses some of the important program features/factors to consider when choosing which program to use.

PROGRAM OVERVIEW

Development and Modeling Approach

TRANSYT-7F, short for TRAffic Network StudY Tool, was developed in the 1970s at England's Transport and Road Research Laboratory and "Americanized" for the Federal Highway Administration. This study used release 8.2a (V 8.27). Its underlying modeling approach is deterministic and macroscopic; however, it does consider the effects of platoon dispersion within the traffic stream. TRANSYT-7F performs simulation and optimization of signalized arterial networks.

Synchro was developed in the mid-1990s by Trafficware. This study used version 4 (Build 220). Synchro performs simulation and optimization, and is also based on a deterministic and macroscopic modeling approach. Synchro does not go to the same level of detail as Transyt-7F in simulating traffic flow, such as platoon dispersion and upstream to downstream origin-destination patterns. It instead relies more on analytical relationships for estimating these effects.

The Highway Capacity Software (HCS) is a software implementation of the procedures in the Highway Capacity Manual (HCM). Specifically, the relevant HCM chapter for this study is chapter 9, Signalized Intersections. This study used version 3.1c (based on the 1997 HCM). The Transportation Research Board (TRB) produces the HCM, and the HCS is produced by *McTrans*. HCM/S uses an analytic, macroscopic modeling approach. It is best suited for analyzing isolated intersections. The methods of chapter 9 do not explicitly model signal coordination; but, the methodology does include a factor to account for different levels of platoon progression that might be expected with coordination.

Input Requirements and User Interface

For TRANSYT-7F, input data are coded in an 80-column format, facilitated by a new data input interface program that runs in the Windows environment. This new interface is a functional replacement for the previous Data Input Manager (DIM), but considerably enhanced. Like the DIM, though, all data must still be coded numerically in a series of records. The amount of input data needed by TRANSYT-7F is extensive. Although simulation or optimization runs do not require much time for execution with typical computer hardware, the input file coding time can be very significant, especially for large networks. One thing to note is that TRANSYT-7F does not compute adjusted volumes or saturation flow rates, so these must be determined externally (e.g., through HCS).

Synchro uses a mouse- and menu-driven input method, allowing the user to "click and drag" to create links (nodes are created implicitly). It also allows the use of a "background" Drawing Exchange Format (DXF) file to use as a template for tracing the street network. Not only does this method make for easy network coding, but it also produces a graphical representation of the network that can be used in reports and presentations. This graphical input method is very intuitive and user-friendly. The overall input data requirements for Synchro are similar to those for TRANSYT-7F. One significant difference is that Synchro does not request information for upstream link input volumes to downstream links. This is because Synchro does not consider platoon dispersion. Once the network has been created graphically, the remaining data are input

in a format that basically mirrors the HCM worksheets, with an additional worksheet for actuated operations. A key feature of Synchro is that most of its calculations and analysis results are updated immediately following changes to user-adjustable values.

HCS Version 3.1c is completely Windows™ based. The input requirements for the HCS are the same as those for the HCM chapter 9.

Output Capabilities and Format

TRANSYT-7F produces all of its output in the form of either 80- or 132-column text files. It generates all standard measures of effectiveness (MOEs). It reports these for each individual intersection, as well as for user-defined routes and the entire network. It also reports all pertinent individual signal and system-wide parameters (e.g., splits, offsets, etc.) determined through optimization. Other optional outputs include flow profile, time-space, time-location, and platoon progression diagrams. These diagrams are somewhat rudimentary in that they use text symbols to create their image, and the resolution is relatively low.

Synchro offers essentially the same menu of MOE outputs as TRANSYT-7F. The user can read basic operational analysis information directly from the input screens as parameter values are entered or changed. The user can also query the program for one or more “reports” of any operational statistic the program computes. Reports can be customized to aggregate statistics by lane group, approach, intersection, arterial, or network, and can include any, or all, applicable measures. Synchro can also create interactive time-space diagrams that can be modified by clicking and dragging various elements of the diagram, with immediate results. For example, the user can modify an intersection’s offset value “on-the-fly” and see the effect on progression right in the diagram.

The reports generated by HCS mimic the HCM worksheets of chapter 9.

PROGRAM METHODOLOGIES

This section describes the underlying methodologies of the programs in regard to signal delay, the modeling of actuated control, and optimization objective functions.

Signal Delay

Generally, in signalized intersection analysis, intersection control delay to vehicles is the primary measure of interest. The following subsections review the signal delay models used within the three programs.

HCS

HCS uses the formulation contained in chapter 9 of the 1997 Highway Capacity Manual. The basic formulation is shown in equation 1.

$$d = d_1 PF + d_2 + d_3 \quad (1)$$

The detailed equations for d_1 , PF , and d_2 can be found on page 9-28 (eqns. 9-23 - 9-25) of the 1997 HCM. The methodology for estimating d_3 can be found in Appendix VI (page 9-139) of the 1997 HCM.

In qualitative terms, the d_1 component accounts for delay assuming uniform arrivals, while the d_2 component accounts for incremental delay due to random and oversaturation queues. The effects of signal progression are accounted for with the progression adjustment factor (PF), which directly impacts uniform delay. The term d_3 accounts for residual demand delay that may be present at the beginning of the analysis period. The traffic conditions for this study did not require the incorporation of the d_3 component into the analysis.

TRANSYT-7F

TRANSYT-7F estimates uniform delay by integrating the number of queued vehicles over the entire cycle, with a queued vehicle defined as one that is not moving at cruising speed. This method explicitly takes into account the effects of progression (via simulation). This is expressed mathematically in Equation 2.

$$D_u = \frac{\sum_{t=1}^N m_t}{N} \quad (2)$$

where:

D_u = uniform delay in veh-hr/hr;
 m_t = queue length in vehicles during time step t ; and
 N = number of steps in the cycle.

Multiplying D_u by 3600 seconds/hour and dividing by the number of vehicles/hour on the approach yields the average delay per vehicle in seconds.

If the default simulation resolution of 1 second/step is used, the results for the d_1 component of uniform delay will very closely approximate the results given by the 1997 HCM formulation for d_1 . The incremental component of delay (d_2) is calculated according to the second term of the 1997 HCM delay equation.

The Transyt-7F “equivalent” of HCM’s progression adjustment factor (PF) is not separately calculated by Transyt-7F. However, a very good estimate can be made by dividing Transyt-7F’s uniform delay measurement (converted to sec/veh) by the d_1 value calculated with the 1997 HCM formulation.

Synchro

Synchro offers the user a choice between two types of signal delay calculations: 1) the 1997 HCM formulation (which it calls Webster’s delay), and 2) percentile delay.

Like Transyt-7F, Synchro also integrates the area under the arrival-departure curve to calculate uniform delay, using a 0.1 second time slice resolution. This method, again, explicitly accounts

for the effects of coordination. The d_2 component of delay is calculated according to the 1997 HCM formulation.

The progression adjustment factor reported by Synchro is calculated according to equation 3.

$$PF = \frac{\text{DelayCoord}}{\text{DelayUnCoord}} \quad (3)$$

where:

DelayCoord = uniform delay calculated with coordination

DelayUnCoord = uniform delay calculated assuming random arrivals

This is the same formula used to calculate the PF “equivalent” for Transyt-7F, with the DelayUnCoord term being calculated according to the 1997 HCM formulation for d_1 .

For the Percentile Delay methodology, the main distinction is in how it models the traffic volume. The HCM method utilizes a constant traffic volume for the entire hour, or peak 15 minutes. The Percentile methodology uses five different traffic volume loadings—10th, 30th, 50th, 70th, and 90th-percentile—based on a Poisson distribution. These loadings are used for the 15-minute analysis period (they are adjusted by the PHF) to calculate a volume weighted delay measurement. Essentially, this technique is intended to more realistically model traffic demand variability experienced from cycle to cycle. These multiple volume scenarios are also used in the calculation of green times for actuated signals. This, in combination with the ability of actuated signals to respond more efficiently to variable traffic loadings, usually results in more accurate modeling of actuated signals. Nearly- and over-saturated conditions can also result in significant differences between the Percentile and HCM delay estimation methods.

Modeling of Actuated Control

The modeling of pretimed signal operation is fairly straightforward since phase times are fixed at the same length for every cycle. Modeling actuated operation is a more complicated task.

HCS

HCS uses a k -factor in the incremental delay (d_2) portion of the total delay formulation to account for control type. For pretimed control, k defaults to a value of 0.5. For actuated control, the k -value is dependent on the unit extension and volume-to-capacity ratio.

HCS does not perform any estimation of green times for actuated control. The green times must be specified directly by the user. Appendix II of HCM’s Chapter 9 provides guidelines for estimating green times for actuated control.

TRANSYT-7F

TRANSYT-7F uses the same random delay (d_2) model as HCS when modeling actuated conditions; but furthermore, it employs its own actuated green time estimator. This actuated green time estimation methodology was originally developed by the Institute of Transportation Studies (ITS) at UC Berkeley. The methodology relies on a user-specified desired degree of saturation for the actuated approaches. The methodology will estimate the average green times

for actuated conditions and then TRANSYT-7F will use these average green times in an equivalent pretimed manner for simulation purposes.

Synchro

Synchro also employs its own green time calculator for actuated conditions. It estimates green times for each of the five different percentile volume loadings according to the Poisson distribution. Synchro uses formulas, which are based on the inputs from the actuated controller settings input page, to predict phase gapping and skipping probabilities for each of the five volume scenarios, and adjusts the average green times accordingly. The delay is calculated for each volume scenario and then averaged across all five volume loadings to determine the overall signal delay under actuated conditions. The Synchro documentation states that its estimated actuated green times will be similar to those determined according to the procedures of HCM, Chapter 9, appendix II.

It should be noted that since HCS nor TRANSYT-7F handle dual-ring controllers, trying to compare actuated results by directly entering the same actuated timings into each program may not be possible for some situations. Synchro, however, does handle dual-ring controllers, which allows it to accommodate overlapping phases.

Optimization Objective Functions

TRANSYT-7F and Synchro are both designed to optimize signalized arterial networks. They are capable of computing signal timings and offsets as dictated by an optimization objective function. HCS does not have any optimization capabilities built-in. The following section will describe the optimization capabilities and objective functions of TRANSYT-7F and Synchro. One thing to keep in mind is that neither TRANSYT-7F nor Synchro perform an exhaustive search of the objective function and thus are only guaranteed to find a local optimum—possibly, but not necessarily, finding the global optimum.

TRANSYT-7F

The objective function, generally called the performance index (PI) can take on several formulations:

1. A simple combination of several MOEs, called the disutility index (DI). This objective function is a basic combination of stops and delay, with the addition of a queuing penalty. If desired, the user can also include link specific weighting factors in various ways to customize the objective function. The basic form of this function is shown below.

$$DI = [\text{delay (veh-hr)}] + [\text{stop penalty} * \text{stops (stops/sec)}] + [\text{queue penalty} * (\text{excess queue (veh)})^2].$$

2. Progression opportunities (PROS). This function tries to maximize the total number of progression opportunities for vehicles. This is similar to maximizing bandwidth. This function can also be used in combination with the DI.
3. There are also four other objective function formulations available, utilizing combinations of the DI, PROS, queuing, throughput, and cost.

TRANSYT-7F will also perform a search for the best cycle length (within a user-specified range) according to the user-specified PI, and then determine the appropriate phase lengths, and coordination offsets for that cycle length. Phase order is not adjustable during this process.

Synchro

Like TRANSYT-7F, Synchro uses a “performance index” for its optimization objective function. In simple notation, this objective function has the following form:

$$PI = \frac{\text{Percentile Signal Delay (sec)} * 1 + \text{Stops} * 10 + \text{Queue penalty (vehs affected)} * 100}{3600}$$

In addition, the percentile delay and PI count an unserved vehicle as contributing 450 seconds of delay. This objective function is similar to, but not the same as, the basic DI objective function within TRANSYT-7F. Its main emphasis is on reducing delay. Unlike the flexibility of the objective function specification within TRANSYT-7F, the components of Synchro’s objective function cannot be directly altered.

Synchro can also perform a search for the best cycle length (within a user-specified range), and determine appropriate phase lengths and coordination offsets for this cycle length, and also evaluate different lead/lag phase orderings. Synchro can also perform separate optimizations on different sub-groupings of intersections within the overall network. The sub-groupings can be user-specified or program-determined based on user-specified coordination factor thresholds.

CASE STUDY

Network Description

A central east-west arterial (NE 45th Street) connecting the University of Washington with Interstate 5 was chosen for the study section. The study section was bounded by 15th Avenue NE on the east and 5th Avenue NE on the west, spanning a distance of approximately 823 meters (2700 feet). One signalized intersection to the north, and one to the south were included in the network. These signals were adjacent to NE 45th Street and are present on heavily traveled connecting streets. Generally, this section consists of two travel lanes in each direction, with left-turn bays or a center two-way left turn lane. Overall, ten signalized intersections were included in the network. Most of the signals are spaced about 85 meters (280 feet) apart. A depiction of the network as shown in Synchro, overlaid on the DXF file supplied by the City of Seattle, is shown in Figure 1.



Figure 1. Network Representation

At the time of study, this arterial was using signal coordination for the eight signals to the east of the interchange signals. The freeway interchange signals were not coordinated with the others due to jurisdictional differences. All of the intersections were under actuated control, which essentially functions as semi-actuated control under coordination.

Collected Data

This study considered only weekday PM peak conditions. The following data were collected for the case study (source in parentheses):

- Signal timings (City of Seattle, field measurement)
- Traffic volumes (City of Seattle, WSDOT)
- Lane channelization (City of Seattle, field measurement)
- Bus stops and bus volumes (field observation, METRO transit tables)
- Travel time (field measurement)
- General queuing conditions (field observation)

Input Data Set

The input traffic conditions were derived from the measured travel times, balanced demand volumes, and observed queues. The infrastructure information (e.g., signal timings and lane channelization) was derived from City of Seattle supplied information and field verification. Grade (slope) values and detector locations were estimated based on the authors' judgment and knowledge of the study area.

A restriction with TRANSYT-7F required a modification to the base data set. The two signals at the freeway interchange were operating on a 150-second cycle length, while all the other intersections were operating on a 120-second cycle length. Since TRANSYT-7F can only simulate one cycle length for the whole network (for systems that include coordination), the signal timings at these two intersections were reduced to 120 seconds. The individual phase lengths were all reduced proportionately. Although Synchro is capable of modeling differing cycle lengths within a network, the changes were made to keep the input files consistent so that the program comparisons would be based on the same set of input conditions.

Program Data Entry

The base data were entered directly into Synchro. The TRANSYT-7F input data set was generated from Synchro and reviewed for consistency. The HCS input files were also generated from Synchro and reviewed for consistency. The input file conversions from Synchro were not perfect in either case and did require some minor modifications to maintain consistency.

Network Calibration

The intent of the calibration was not to replicate the exact conditions observed on any one particular day, but to simulate a set of average traffic conditions that might normally be expected on any given day for this arterial. If the input traffic data were reasonable for the study section, and the same for all programs, then comparisons between the programs could be facilitated.

Network calibration was checked using Synchro. The original input data set, with minor adjustments, resulted in an acceptable level of calibration. This same data set was then also used for TRANSYT-7F and HCS.

While traffic conditions would be qualitatively described as moderately congested, the highest v/c ratio for any approach was 0.97. Thus, existing conditions were operating near or below capacity.

Signal Delay Estimation Results

To ensure that green times were consistent between all three programs, the signal delay comparisons were performed using pretimed control. For this arterial, that resulted in the minor approaches using their specified maximum green times.

The signal delay estimates reported by HCS, TRANSYT-7F, and Synchro for each individual intersection are shown in Figure 2.

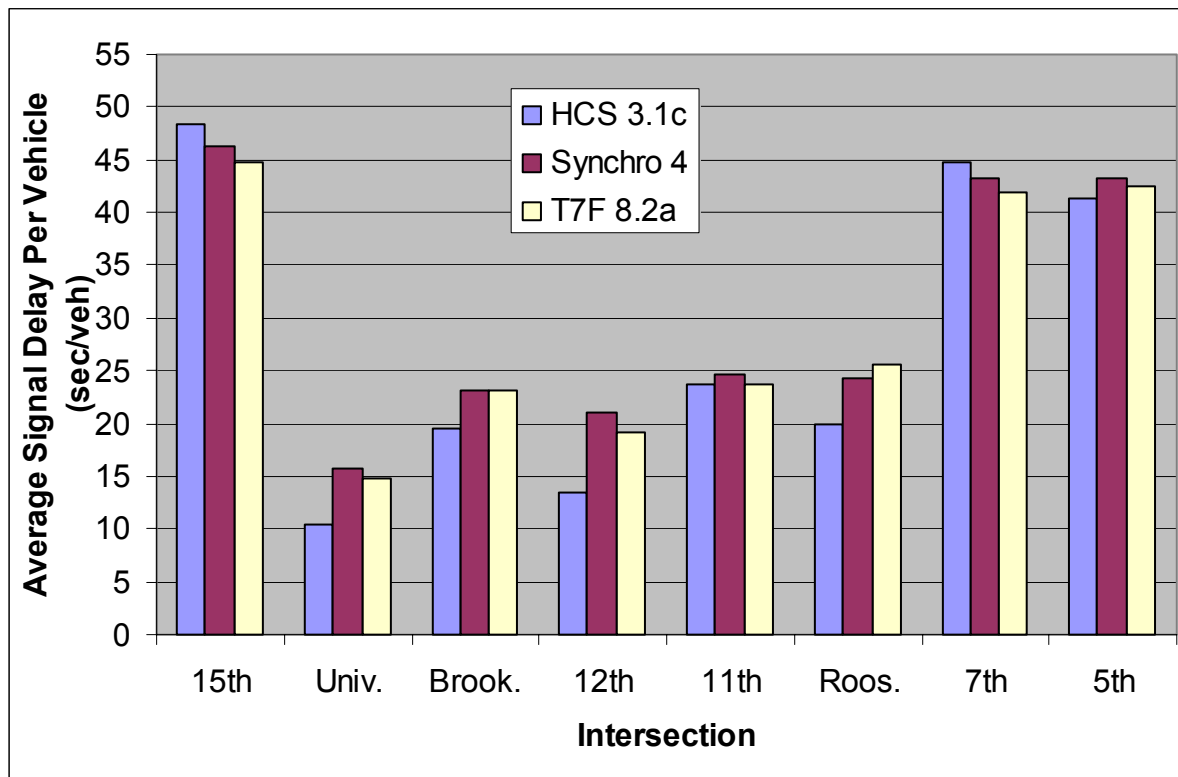


Figure 2. Signal Delay Comparison

The results are first presented in this graphical format rather than tabular format to provide an overall picture of the results rather than focusing on the specific delay values themselves. This figure shows that there are obvious differences in the delay estimates between the three programs. To gain further insight into the source of the differences, three intersections (University, 12th, Roosevelt) with varying characteristics were chosen for a more detailed analysis. Table 1 displays the values for all the key parameters that impact signal delay for these intersections. Parameter values that were considerably different between programs are highlighted. Very small differences in table values (on the order of 0.1 – 0.2) are generally a result of rounding differences.

Table 1. Signal Delay Comparison at Selected Intersections

University Way																		
Lane Group	v/c			g/C			Delay Terms											
							d ₁			Prog. Factor			d ₂			Total (sec)		
	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F
NB Thru	0.57	0.57	0.57	0.333	0.33	0.333	33.0	32.9	32.9	1.000	1.00	1.00	4.9	4.9	4.8	37.8	37.8	37.8
NB Rt	0.17	0.17	0.17	0.333	0.33	0.333	28.3	28.3	28.3	1.000	1.00	1.00	1.2	1.2	1.3	29.4	29.4	29.5
SB Thru	0.39	0.39	0.39	0.333	0.33	0.333	30.7	30.7	30.7	1.000	1.00	1.00	2.4	2.4	2.4	33.1	33.1	33.1
SB Rt	0.31	0.31	0.31	0.333	0.33	0.333	29.7	29.7	29.7	1.000	1.00	1.00	2.5	2.5	2.6	32.3	32.3	32.3
EB TR	0.94	0.94	0.94	0.583	0.58	0.583	22.9	23.0	23.1	0.000	0.16	0.14	5.5	7.1	5.5	5.5	10.7	8.8
WB TR	0.85	0.85	0.85	0.583	0.58	0.583	20.7	20.7	20.7	0.067	0.44	0.42	2.4	3.0	2.4	3.7	12.1	11.1
Overall																10.4	15.8	14.7
12 th Avenue																		
Lane Group	v/c			g/C			Delay Terms											
							d ₁			Prog. Factor			d ₂			Total (sec)		
	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F
NB LTR	0.25	0.25	0.25	0.208	0.21	0.208	39.7	39.7	39.7	1.000	1.00	1.00	1.9	1.9	1.9	41.6	41.6	41.6
SB LTR	0.18	0.18	0.18	0.208	0.21	0.208	39.1	39.1	39.1	1.000	1.00	1.00	1.3	1.3	1.3	40.4	40.4	40.4
EB L	0.97	0.97	0.97	0.075	0.08	0.075	55.4	55.4	55.4	1.000	1.04	1.06	51.7	62.1	52.3	117.1	119.7	111.0
EB TR	0.91	0.91	0.91	0.592	0.59	0.592	21.7	21.7	21.7	0.034	0.47	0.41	4.5	6.1	4.6	6.8	16.3	13.6
WB L	0.20	0.20	0.20	0.075	0.08	0.075	52.1	52.1	52.1	1.000	0.95	1.10	2.5	3.0	2.5	55.4	52.8	60.0
WB TR	0.70	0.70	0.70	0.592	0.59	0.592	17.1	17.1	17.1	0.595	0.80	0.76	1.5	1.8	1.5	12.1	15.5	14.5
Overall																13.5	21.1	19.1
Roosevelt Way																		
Lane Group	v/c			g/C			Delay Terms											
							d ₁			Prog. Factor			d ₂			Total (sec)		
	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F	HCS	Synchro	T7F
SB L	0.22	0.22	0.22	0.217	0.22	0.217	38.7	38.6	38.7	1.000	0.88	0.86	1.4	1.4	1.4	40.0	35.2	34.6
SB Thru	0.97	0.97	0.97	0.217	0.22	0.217	46.7	46.6	46.6	1.000	0.90	0.91	27.1	27.0	27.2	73.8	69.1	69.4
SB R	0.42	0.42	0.42	0.217	0.22	0.217	40.5	40.5	40.5	1.000	0.88	0.87	4.6	4.6	4.6	45.1	40.1	39.8
EB TR	0.89	0.89	0.89	0.583	0.58	0.583	21.7	21.7	21.7	0.067	0.44	0.44	6.6	6.0	6.7	7.5	15.5	16.3
WB L*	0.42	0.65	0.71	0.692	0.70	0.692	10.3	21.5	11.2	0.290	0.76	3.79	2.3	10.2	12.6	5.3	26.6	54.9
WB Thru	0.72	0.72	0.72	0.700	0.70	0.700	10.9	10.9	10.9	0.000	0.44	0.45	1.6	1.9	1.6	2.0	6.6	6.5
Overall																20.0	24.2	25.6

* permitted + protected phasing

Review of the table indicates that most of the differences in total delay are related to the progression factor (PF). This is a natural result because rather than classifying traffic flow as one of six different arrival types, as HCS does, TRANSYT-7F and Synchro explicitly account for the traffic progression between intersections. Essentially, the only approaches that can be expected to have the same progression factor between programs are those that have random arrivals (arrival type 3 in HCS), where the progression factor will be 1.0. For a coordinated arterial, these approaches are typically on the cross streets. In some cases, left turn movements may also have similar progression factors (i.e., ≈ 1.0) because left turns are typically not coordinated movements. Although HCS will accept a 'percent of vehicles arriving on green' value instead of an estimated arrival type, this requires more extensive data collection than is usually conducted. The southbound movements for Roosevelt Way have PF s other than 1.0 in TRANSYT-7F and Synchro because of an upstream coordinated intersection. But despite some actual positive coordination effects due to the upstream signal, HCS still estimated PF s of 1.0 for the southbound movements due to its rough approximation of traffic arrivals.

The estimation of d_1 between all three programs was very consistent overall. The biggest discrepancy was for the westbound left turn movement at Roosevelt Way. This difference was primarily due to different permitted left turn factors between the programs. The phasing for this movement is permitted + protected. The default permitted left turn model for TRANSYT-7F is one developed by the Australian Road Research Board (ARRB). An HCM permitted left turn model can be specified for TRANSYT-7F, but this model still conforms to the 1985 HCM specification, which is significantly more simplistic than either the 1994 or 1997 versions. Synchro now implements a permitted left turn model that is structurally similar to the 1997 HCM model. However, there are parameter values within the permitted left turn model that may vary due to other differences in the programs that will still lead to different f_{LT} 's between the two programs. Additionally, for actuated conditions, f_{LT} is calculated based on maximum green times rather than actuated green times. This may also cause the Synchro f_{LT} to vary slightly from the HCM calculations.

The random delay component (d_2) was very consistent between all three programs for the cross-street links. For the main street links, HCS and TRANSYT-7F were very consistent with each other, while Synchro varied slightly. The only significant difference in d_2 between HCS and TRANSYT-7F occurred for the westbound permitted + protected left-turn movement at Roosevelt Way. This can be explained by the very different volume-to-capacity (v/c) ratios between the two programs. The variance in d_2 between Synchro and HCS for the main street links was due to the I -factor. The I -factor accounts for upstream filtering and metering effects. For external links, the I -factor is assumed to equal 1.0. All three programs actually use different rules for calculating the I -factor. According to the terse guidance given in the HCM in regard to the I -factor, ' I ' should be set equal to 1.0 for isolated intersections (the guidance given in chapter 9) and should be calculated using the upstream through movement v/c ratio for an arterial of intersections (the guidance given in chapter 11). However, given that the methodology of HCM chapter 11 (Arterials) only deals with through movements, the upstream through movement v/c ratio is the only choice for use in calculating the I -factor. TRANSYT-7F uses the v/c ratio for the upstream movement (that feeds the downstream link) having the largest traffic volume (which is usually the through movement) in its I -factor calculation. Note that this is the rule used in release 8.2a. Release 8.2 used a different rule that was later determined to not be consistent with the original intent of the I -factor. Current users of 8.2 should update to 8.2a—see the McTrans website for the 8.2a patch. Synchro uses a volume weighted v/c ratio of all upstream

links that feed the downstream link. For more information on the I -factor, see Fambro and Rouphail (5). Nonetheless, the differences in d_2 due to the I -factor were usually minor between Synchro and HCS. The obvious exception again was the westbound left-turn movement at Roosevelt Way, which was due mostly to the different v/c ratios.

Another potential source of variance can result from Synchro's capability of modeling right-turns-on-red (RTOR). Synchro explicitly determines a RTOR saturation flow rate, whereas HCS and TRANSYT-7F do not. For the purposes of consistency in this study, RTORs were not modeled in Synchro. And another potential variance item of note is that TRANSYT-7F uses the 1985 HCM formulation for the calculation of d_2 for links that are declared shared on a record type 7.

SIGNIFICANT PROGRAM FEATURES

This section briefly lists and describes some of the main program features and/or factors in TRANSYT-7F and Synchro that should be considered when choosing which program to use for a particular study.

TRANSYT-7F

- Takes platoon dispersion into account for simulating traffic flow. This results in a more realistic representation of the flow of traffic along an arterial.
- Ability to define special lanes for modeling, such as transit-only lanes, or mixed-flow lanes with separate MOEs.
- Step-wise simulation capability added as an option to the standard link-wise simulation mode. The step-wise mode is especially suited for the modeling of over-saturated conditions.
- The option to specify multi-cycle modeling instead of single-cycle. Multi-cycle simulation is recommended for modeling uncoordinated operations, congested conditions, and multiple periods.
- Tremendous flexibility in defining the optimization objective function. This is clearly one of the greatest strengths of TRANSYT-7F. The user can optimize signal settings for many different objectives—progression opportunities, stops, delay, fuel consumption, queue lengths, and others. Combined with the ability to specify weighting factors for individual factors and links, the optimization objective function specifications are extensive.

Synchro

- Ability to simultaneously optimize lead-lag phase ordering in addition to cycle length, phase lengths, and coordination offsets.
- Separate optimization of multiple sub-areas defined within the overall network. This feature allows one to separately optimize different groups of signals within the overall

network. Consequently, Synchro allows different cycle lengths within the same coordinated network.

- Percentile Delay estimation methodology. Provides an alternative methodology that attempts to model the effects of actuation and coordination in a more realistic manner.
- Easy data input. Comprehensive output options.
- Capability of modeling right-turns on red, u-turns, and five-legged intersections.
- Multiple intersections can be controlled by a single controller, simplifying the process for modeling situations like diamond interchanges.
- Optimization objective function is very rigid. Currently, the only optimization option available is to minimize delay.

SUMMARY

As the results in this paper suggest, even with identical input data, differences between HCS, TRANSYT-7F, and Synchro can be expected. The only situation in which identical results can be expected is an intersection that is pretimed, has random arrivals on all approaches, and all movements are protected. Differences in delay estimates between the three programs are mainly due to the Progression Factor and *I*-factor. Differences can also occur for permitted left-turn movements due to different permitted movement models and/or different assumptions about the values of some of the parameters used in those models. Differences will also occur if the RTOR modeling capability is used within Synchro.

Synchro's Percentile Delay option allows the user an alternative way to estimate intersection control delay. The Percentile method allows actuated conditions and coordination to be modeled in more detail. However, this method of delay calculation is generally not recognized (i.e., accepted) by public agencies for traffic impact studies. Thus, this method may be of most use for just evaluating the relative differences to be realized from various actuated and coordinated conditions, not for reporting to public agencies.

Each program has strengths and weaknesses, and neither is ideal for every situation. The analyst should carefully consider how each program's characteristics mesh with the study section characteristics and project objectives when making a decision as to which program to use for a particular study. HCS is recommended for situations in which you are analyzing only a truly isolated intersection and/or a public agency specifically requires HCS reports for traffic studies.

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