13 SIGNALIZED INTERSECTION ANALYSIS

13.1 Purpose

This chapter presents commonly used signalized intersection deterministic analysis procedures and identifies specific methodologies and input parameters to be used on ODOT projects. Simulation procedures are covered in APM Chapter 15. Software settings are covered in Appendix 12/13. Topics covered include:

- Turn Lanes at Signalized Intersections
- Auxiliary Through Lanes
- Signalized Intersection Capacity Analysis
- Signal Progression Analysis
- Estimating Queue Lengths at Signalized Intersections

> *The scope of this chapter is limited to auto mode analysis at signalized intersections. A complete evaluation of signalized intersections requires a broader evaluation including of non-auto modes. Refer to APM Chapter 10 for modal considerations such as for left and right turn lanes, and to Chapter 14 for multimodal analysis procedures such as MMLOS. The need for other evaluations such as per the Traffic Manual and HDM should be coordinated with Region Roadway/Traffic or Traffic Engineering Section.*

13.2 Criteria for Turn Lanes at Signalized Intersections

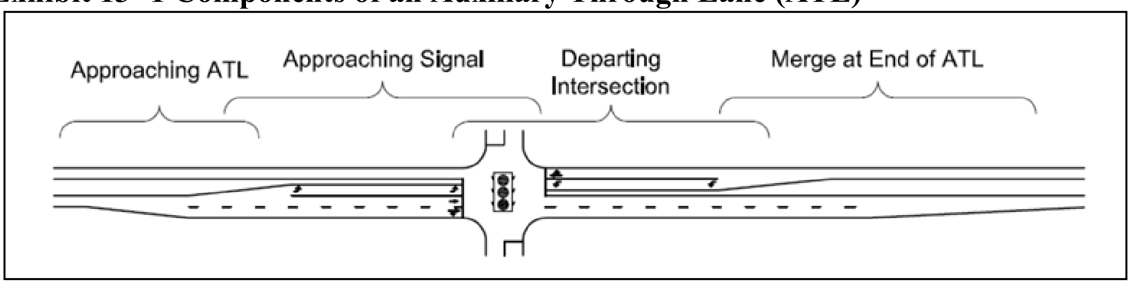
Turn lanes at signalized intersections are determined differently than at unsignalized intersections. At signalized intersections a left turn lane is always desirable, while a right turn lane is generally determined based on signal capacity needs. At signalized intersections, installation of turn lanes must be consistent with the requirements in ODOT's Traffic Signal Policy and Guidelines and the Traffic Manual and approval must be received.

13.3 Auxiliary Through Lanes at Signalized Intersections

The following procedure is intended for the analysis of existing ATLs only. Installation of an Auxiliary Through Lane (ATL) on a state highway is generally not allowed. ODOT has reviewed NCHRP Report 707 Guidelines on the Use of Auxiliary Through Lanes at Signalized Intersections. While the document provides discussion about the use of auxiliary through lanes and creates a potential process to follow when considering installing an auxiliary through lane, it was found the research and analysis was neither comprehensive nor definitive enough to fully support the recommendations. Therefore, the installation of an auxiliary through lane on the state highway system will require approval from the State Traffic Engineer and will be considered on a case-bv-case basis.

An Auxiliary Through Lane (ATL) is a limited length through lane added midblock upstream and downstream of a signalized intersection (Exhibit 13- 1). Configurations different than shown in the exhibit, including when accesses are present, are not considered ATLs and are add/drop lane areas instead, which are not covered in this section. Typically, the ATL form has been used as a way to meet an operational standard with future street widening deferred to a later date. ATLs are more commonly found on local rather than state facilities.

Exhibit 13- 1 Components of an Auxiliary Through Lane (ATL)



13.3.1 ATL Issues

There are several issues regarding ATLs and transit, access points, pedestrians and bicycles and other conditions. Overall, ATLs are discouraged and in some cases should be reconfigured. A few of the issues are identified below:

- Access points within ATLs can be both safety and operational concerns.
- Pedestrian crossing distance and time is longer at an ATL, which can lead to longer exposure, cycle times and increased delay.
- Transit stop locations can be a problem within ATLs. Without a transit pull-out, the presence of a bus will reduce ATL utilization.
- Some ATLs may be used as a passing lane, causing a safety concern in the speed differential between the two lanes during congested hours.

13.3.2 ATL Analysis

As noted above, in the review of NCHRP Report 707, ODOT does not fully support recommendations regarding the NCHRP 707 (1) procedure for estimating the lane utilization, taper length, or prescribed length of an ATL.

For analysis of an existing ATL, the lane utilization should be measured in the field if possible. If the lane utilization cannot be measured, assume a lane utilization of 15% for a shared ATL with one continuous through lane, 12% if two continuous through lanes exist. Add 3% for an exclusive right turn lane.

To analyze the adequacy of the taper or ATL length, such as for performing microsimulation, the analyst needs to work with the designer to determine what lengths should be used. This may be an iterative process where the analyst runs the analysis with several different lengths to determine the impact of length on the analysis results.

13.4 Signalized Intersection Analysis

Signalized intersection control can generally be classified into three categories; pre-timed, semi-actuated and fully actuated operations. A pre-timed signal has the cycle length, phases, green times and change phases all preset to be constant for every cycle. A semi-actuated signal operates by designating a "main street" that is served until actuation from the "side street" occurs. Under this type of operation, the cycle length and green times may vary based on vehicle demand. ODOT has effectively upgraded all formerly semi-actuated intersections to fully actuated. A fully actuated signal allows detection on all legs and phases of the intersection and cycle lengths and green times are determined based on the demand for each movement.

In addition to the type of signal operating, each signalized intersection has characteristics associated with it related to how the timing of a signal is allocated over a cycle. These characteristics relate to phases, intervals, change intervals, green time, lost time, yellow and all-red clearance times and effective green time. All these characteristics can be part of signalized operations and can affect the overall intersection operations. For more information on characteristics of signals and signal operations analysis, refer to Chapter 19 of the HCM.

13.4.1 Saturation Flow Rates

As previously discussed in Chapter 3, saturation flow rates are critical components in the analysis of signalized intersection capacity and can be defined as the flow in vehicles per hour that can be accommodated by a lane group assuming that the green phase is displayed 100 percent of the time. Saturation flow rates can be measured in the field or calculated by applying adjustment factors to a default "ideal" saturation flow rate. For more information regarding the calculation and application of saturation flow rates, refer to Chapter 3.

Chapter 31 of the HCM 7th Edition provides adjusted saturation flow rates for through movements, along with saturation flow adjustment factors for protected and permitted left turns, that reflect the presence of connected and automated vehicles (CAVs) in the traffic stream. CAVs offer the potential to increase the saturation flow rate by being able to cooperatively form platoons that have shorter headways between platooned vehicles than human-driven vehicles can achieve safely. These shorter headways allow more vehicles to enter an intersection per hour of green time, increasing the capacity of through and protected left movements. In addition, they can result in longer gaps in opposing traffic that can be used by permitted left-turn movements. Both effects can result in higher movement capacities, particularly at higher percentages (>60–80%) of CAVs in the traffic stream. Appendix 6B provides guidance on estimating saturation flow rates for use in longer-range planning analyses testing the potential effects of CAVs on signalized intersection and arterial capacity.

As of 2022, no vehicles were available commercially that met the definition of a CAV for the purposes of the capacity adjustments provided for signalized intersection analyses in the HCM (i.e., a vehicle with an operating cooperative adaptive cruise control system that is capable of communicating with other vehicles and driving without human intervention in any situation). The saturation flow rate adjustments presented in Appendix 6B are intended for use only in longer-range planning analyses. That appendix also provides guidance on estimating the percentage of CAVs in the traffic stream in a future year and example problems.

Because CAVs are not yet commercially available, saturation flow rate adjustments for CAVs should not be made in near-term analyses such as traffic impact studies.

13.4.2 Right Turn on Red (RTOR)

Oregon law permits a right-turn movement by a vehicle facing a circular red or a red arrow indication after stopping and yielding to pedestrians and any conflicting vehicles, unless posted otherwise. For future conditions, an engineering study should be performed to evaluate appropriate traffic control options such as RTOR prohibition for safety reasons – contact Region Traffic for guidance. Warrants for turn prohibitions are found in OAR 734-020-0020. Additional guidance is found in MUTCD Section 2B.54. Region Traffic Engineer/Manager approval is required for No Turn On Red signs. The remainder of this section assumes that it has been determined that RTOR will not be prohibited.

For existing conditions, the HCM advises that counts may be used to obtain the RTOR volume, which is then subtracted from the total right turn volume in the analysis. However, it is often not practical to obtain RTOR counts.

For future conditions or where RTOR counts are not obtained, the HCM does not provide a methodology to estimate right turn on red (RTOR) volume. The following options for analysis can be considered.

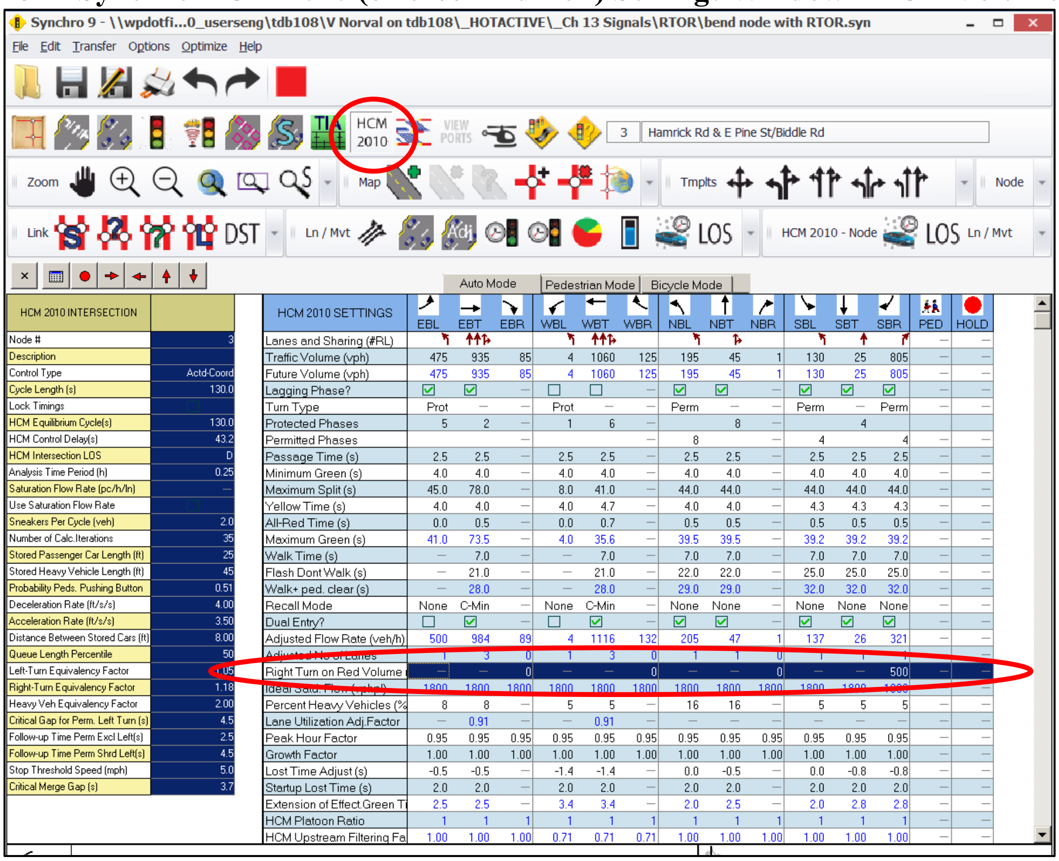
1. No reduction for RTOR – The HCM recommends not applying a reduction for RTOR for future conditions. This provides a conservative result. If v/c ratio and queuing are not an issue, no further RTOR analysis may be deemed necessary; however for simulation

RTOR should be accounted for. The operational benefit of RTOR is a function of the volume of right turns, volume of conflicting traffic and signal timing/phasing.

2. Synchro –RTOR can be enabled by checking the RTOR box in the Lane settings window. In this method, a saturated flow rate for RTOR is calculated. The right turn on red saturated flow rate (sRTOR) is the potential volume if the signal was red 100% of the time. In order to reflect RTOR in the HCM (2010 or later) report, a RTOR volume must be entered in the HCM 2010/6th/7th settings window as shown in Exhibit 13- 2 below. The Synchro estimated RTOR volume (vRTOR) can be obtained from this equation:

   vRTOR = sRTOR * r/C, where r/C is the red to cycle ratio

Exhibit 13- 2 Synchro HCM 2010 (or 6th/7th Edition) Settings Window RTOR Volume



3. SIDRA – Check the Turn on Red Checkbox to identify approaches where RTOR is allowed. SIDRA will then internally calculate and apply the RTOR volume reduction similar to Synchro.

4. Vistro – In Vistro the analyst can select the approaches where RTOR is allowed either using a global setting or by approach. However, Vistro does not calculate the RTOR volume so it must be input manually. First, assume no RTOR and determine if there is a v/c ratio or queuing problem. If no v/c ratio or queuing problem is found, no further analysis is necessary. If a v/c ratio or queuing problem is found assuming no RTOR, options for estimating RTOR in Vistro include using Synchro to obtain the RTOR volume, or one of the following steps.

5. Planning level method for shared through/right lanes - can be used for estimating RTOR volume in Vistro (2). This method addresses only vehicle conflicts with the RTOR movement. It does not address pedestrian conflicts or bicycles in the traffic stream. A significant volume of pedestrians may warrant posting of no right turn on red signage.

   The method estimates RTOR volume using the following model (3).

$$N_{RTOR} = \min(X_r, 1.0) \times \left(\frac{1-p}{p}\right) \times \frac{3600}{C}$$

   where
   - N_{RTOR} = expected number of RTORs for the analysis period (veh)
   - Xr = demand volume-to-capacity ratio for the shared lane subject approach
   - p = proportion of through vehicles shared lane for the analysis period (veh/h)
   - C = average cycle length (s) during the analysis period.

   The RTOR volume is deducted from the total right turn volume.

6. Planning method for exclusive right turn lanes – Assumes 50% of right turn volumes turn right on red, unless high pedestrian traffic or sight distance constraints are present, in which case assume 30% RTOR (4).

7. Wisconsin method for exclusive right turn lanes – Applies a reduction factor to the total right turn volume as follows[1]:
   - Single Right-Turn Lanes at Intersections: 0.62
   - Single Right-Turn Lanes at Interchanges: 0.34
   - Dual Right-Turn Lanes (Intersections and Interchanges): 0.70

Example 13- 1 Planning Level RTOR Method for Shared Through/Right Lane

A two-lane approach has one through lane and one shared through/right lane. The through volume is 760 vph and the right turn volume is 250 vph. The v/c ratio for the shared lane group is 0.97. The cycle length is 100 sec.

Xr = 0.97

Total lane group volume = 760 + 250 = 1010 vph

Assuming balanced lane volumes, the volume in each lane is 1010/2 = 505 vph

Shared lane through volume = 505 – 250 = 255 vph

p = proportion of through vehicles in shared lane = 255/505 = 0.50

[1] https://wisconsindot.gov/dtsdManuals/traffic-ops/manuals-and-standards/teops/16-15.pdf

$$N_{RTOR} = \min(0.97, 1.0) \times \left(\frac{1-0.50}{0.50}\right) \times \frac{3600}{100} = 35 \text{ vph}$$

Therefore, for this example the RTOR volume can be estimated as 35 vph.

13.4.3 Critical Movement Analysis

The critical movement analysis method is a planning-level tool to estimate capacity of a signalized intersection with existing or forecasted volumes. It is for estimation only; not to report final v/c ratios or compare to mobility targets. The analysis requires intersection approach volumes, number of lanes, and lane assignments per approach.

Each movement pair in conflict (e.g. westbound left and eastbound through) are added for a total volume. Identify the highest total (or critical movement pair) for each roadway. If available, use lane utilization for duplicate lane assignments on an approach. If lane utilization data does not exist, then use an even distribution. The critical movement pairs for each roadway are summed and compared with the thresholds shown in .

Exhibit 13- 3 Intersection Performance Assessment by Critical Volume

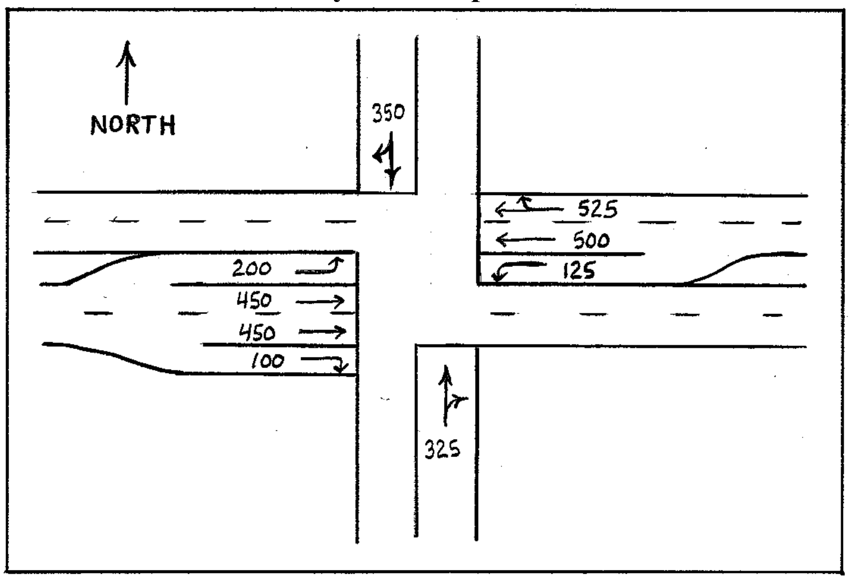
Sum of Critical Volumes (Vehicles/Hour/Lane)	Performance
0 to 1,200	Under Capacity
1,201 to 1,400	Near Capacity
1,401 and Above	Over Capacity

Critical movement analysis only estimates an intersection's capacity. It does not estimate vehicle delay, level of service or vehicle queue lengths.

Example 13- 2 Critical Movement Analysis

The Critical Movement figure shows the signalized intersection of a five-lane highway with a two-lane cross street. For this intersection, conduct critical movement analysis.

Critical Movement Analysis Example



Solution:

For the east-west roadway, the conflict pairs include:

- 200 (EB LT) + 525 (WB TH/RT) = 725
- 200 (EB LT) + 500 (WB TH) = 700
- 125 (WB LT) + 450 (highest EB TH) = 575
- 125 (WB LT) + 100 (EB RT) = 225

The highest conflict pair is EB LT and WB TH/RT. Therefore, the critical movement volume for the east-west roadway is 725 vehicles.

For the north-south roadway, the conflict pairs include:

- 350 (SB TH/RT) = 350
- 325 (NB TH/RT) = 325

For these approaches there are no conflicting movements, thus the highest total approach volume is the north-south critical movement, 350 vehicles. The sum of the critical movement volumes for the intersection:

725 (east-west) + 350 (north-south) = 1,075

Compared to the thresholds shown in , this intersection is estimated to operate under capacity.

13.4.4 Critical Intersection v/c Ratio

For signalized intersections, the reported v/c ratio is based on the critical intersection v/c ratio, not the movement or approach v/c ratio. The OHP refers to the intersection v/c ratio (another name for the critical v/c ratio) in Action 1F.1. However, many software programs (e.g., Synchro, SIDRA, etc.) just show the highest approach or movement v/c rather than the needed intersection or critical v/c ratio and require a separate calculation. The critical intersection v/c ratio is also known as Xc in the HCM. It involves summing the flow ratios of the critical movements. This value is not generally affected by the approach green times (except in cases with shared left turns). See the HCM equation below (note that the critical intersection equation from any edition of the HCM is acceptable).

Critical Intersection Volume to Capacity Ratio (for signalized intersections)

$$X_C = \left(\frac{C}{C-L}\right)\sum_{i \in ci} y_{c,i}$$

With

$$L = \sum_{i \in ci} l_{t,i}$$

Where:

X_C = critical intersection volume to capacity ratio
C = cycle length (sec)
$y_{c,i}$ = critical flow ratio for phase $i = \dfrac{v_i}{(Ns_i)}$
$L_{t,i}$ = phase i lost time $= l_{1,i} + l_{2,i}$ (sec)
ci = set of critical phases on the critical path
L = cycle lost time (sec)
v_i = lane group flow rate for phase i
N = number of lanes for lane group i
s_i = lane group saturation flow rate for phase i

It is important to highlight that ***lane group*** flow rates (v_i) and saturation flow rates (s_i) used for the critical intersection v/c calculation (not movement groups). This may be somewhat confusing as these two designations are very similar. In general, a separate ***lane group*** is created for:

a. each lane (or group of adjacent lanes) that serve one movement, and
b. each lane served by two or more movements.

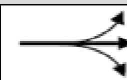
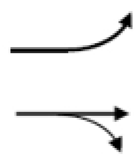
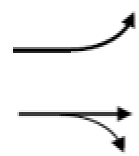
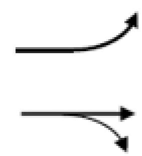
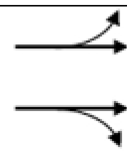
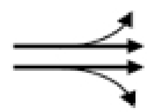
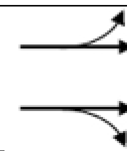
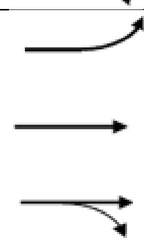
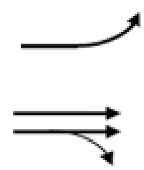
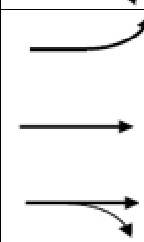
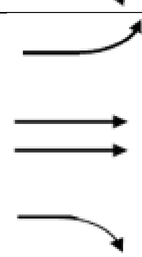
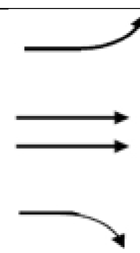
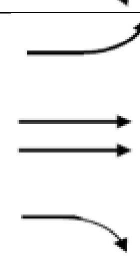
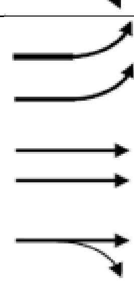
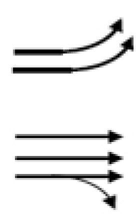
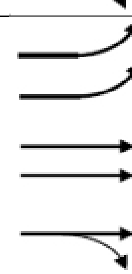
Keep in mind that ultimately lane groups are what is used in the calculation. Movement groups can be considered as a support to the lane group methodology. For example, when there is a shared lane and the through and turn movements must be identified separately (e.g., in the case of permitted turns).

In general, a separate ***movement group*** is created for:

a. each turn movement with one or more exclusive lanes, and
b. the through movement (including any turn movements that share a lane with the through movement).

The difference between the two groups occurs when a shared lane is on an approach with two or more lanes. Some guidance will be provided here but also reference HCM 7 Chapter 19 for detailed discussion. Exhibit 13- 4 shown below provides examples of a variety of typical movement groups and lane groups.

Exhibit 13- 4 Typical Lane Groups

Number of Lanes	**Movements by Lanes**		**Movement Groups (MG)**		**Lane Groups (LG)**	
1	Left, through, and right:		MG 1:		LG 1:	
2	Exclusive left: Through and right:		MG 1: MG 2:		LG 1: LG 2:	
2	Left and through: Through and right:		MG 1:		LG 1: LG 2:	
3	Exclusive left: Through: Through and right:		MG 1: MG 2:		LG 1: LG2: LG 3:	
4	Exclusive Left: Through: Through: Exclusive right:		MG 1: MG 2: MG 3:		LG 1: LG2: LG 3:	
5	Exclusive left: Exclusive Left: Through: Through: Through and right:		MG 1: MG 2:		LG 1: LG2: LG 3:	

Notice that a lane group may include one or more lanes. Use the following rules to determine the lane groups for an intersection approach:

- An exclusive left-turn lane or lanes should be designated as a separate lane group. The same is true of an exclusive right-turn lane.
- Any shared lane should be designated as a separate lane group.
- Any lanes that are not exclusive turn lanes or shared lanes should be combined into one lane group.

A movement group may contain one or more lanes and/or more than one lane moving in more than one direction. Use the following rules to determine the movement groups for an intersection approach:

- A turn movement is served by one or more exclusive lanes, and no shared lanes should be designated as a movement group.
- Any lanes not assigned to a group by the previous rule should be combined into one movement group.

The lane group concept is important to help identify the appropriate flow rate and saturation flow rate from the software reports to use in the flow ratio calculations. If the approach has no shared lanes or has only one lane, the lane group and movement group will both have the same flow rates. An analyst will need to pull the flow rate for each lane and then appropriately combine them for each individual lane group. It is these lane group values that will then be used to calculate the flow ratios used in the critical intersection v/c calculation.

Numerous issues have been noted with the identification of intersection critical movements. Generally, there has been an over-reliance on the critical movement(s) identified by the Synchro and SIDRA reports. The key to identifying critical movements is to use phasing and flow ratios. It is critical to methodically sketch out the identified phasing. Skipping steps and moving directly to an Excel spreadsheet will lead to problems. Once the critical movements have been identified using the highest v/s flow ratios dependent upon the phasing type, the critical intersection v/c ratio can be calculated using the HCM equation.

Phasing and Flow Ratios

The flow ratio calculation depends on summing the lane group flow ratio for each phase.

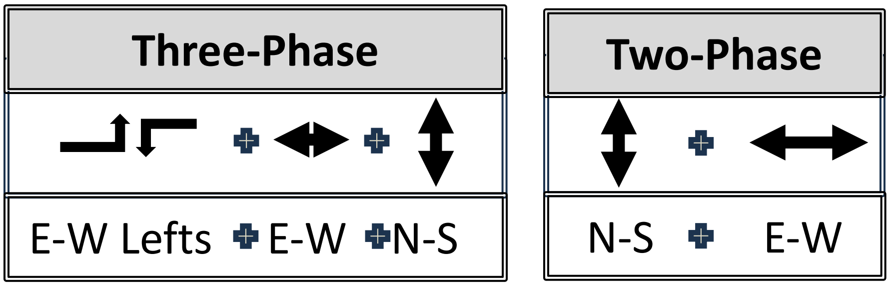
$$Flow\ Ratio = \frac{v}{s}$$

Where:

$$v = \text{volume}$$
$$s = \text{saturated flow}$$

There will be a v/s term for each phase in the total calculation. For example, if there are two phases, then there will be two v/s components; if there are three phases, there will be three v/s components, etc. This is represented graphically in Exhibit 13- 5 below.

Exhibit 13- 5 Number of Phases and Number of Flow Ratios



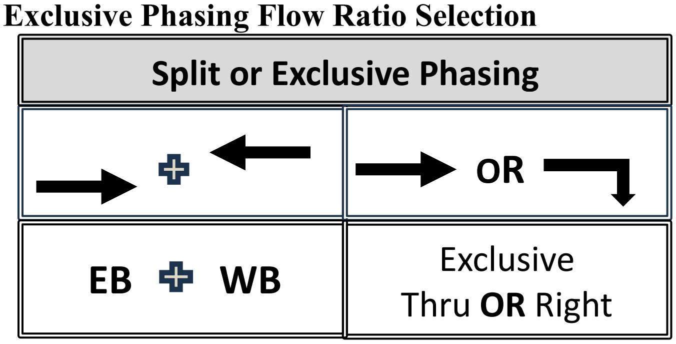
Calculating the v/s ratio for all lane groups will help indicate critical movements/pairs and controlling movements (i.e. exclusive through vs exclusive right) and will be needed in future analysis. Generally, for the critical v/c calculation the highest lane-group v/s will be used for each phase and for each barrier pair the highest combined phase v/s in ring one or ring two will be used. However, each phasing type has a nuanced approach which will be described below.

*It is important to review and sketch out the phase rotation. Also, calculate the v/s for all **lane groups**. Phase rotation may be available on timing sheets. If not, ask Region Traffic or a local contact. Actual phase rotation may not be clearly apparent in the field.*

Split or Exclusive Phasing

For split or exclusive phasing each approach should be treated separately. In this scenario to calculate the critical pair, check whether the through or the right turn movement controls by noting which one has the highest v/s ratio. Either the through or the right will be used in the calculation as depicted in Exhibit 13- 6.

Exhibit 13- 6 Split or Exclusive Phasing Flow Ratio Selection



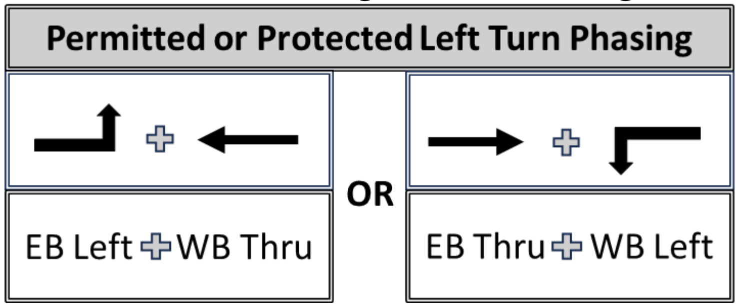
Permitted or Protected Left Turn Phasing

Left turn phasing may be either permitted or protected. For permitted or protected left turn phasing, the phase pair[2] (left and through) with the highest v/s should be used as shown in Exhibit 13- 7. Protected left turn phasing may be in lead-lag (common when one left turn

[2] *Phase pairs are within the same ring and barrier that cannot run concurrently (e.g EB left turn and WB thru)*

movement is significantly higher than the other and is used to optimize timings), lead-lead (most common), or lag-lag patterns.

Exhibit 13- 7 Permitted or Protected Lead-Lag Left Turn Phasing Flow Ratio Selection



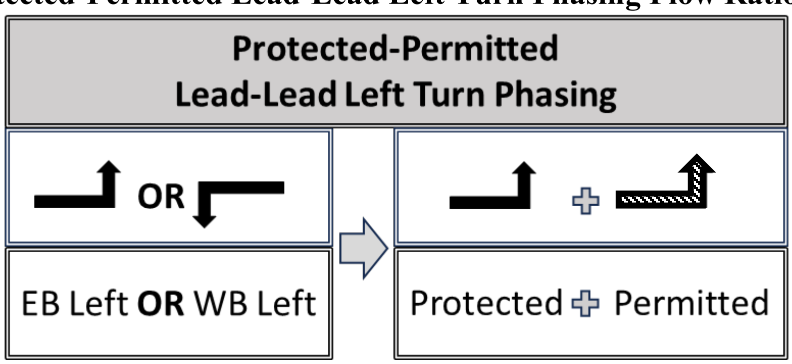
When the left turn phasing is protected, it is important to identify where lead-lag phasing is in use as the automatic Synchro/SIDRA reports may flag multiple left or through movements. Generally, these extra movements are not likely used in the overall v/c calculation.

Protected-Permitted Lead-Lead or Lag-Lag Left Turn Phasing

A more complex situation arises when there is protected-permitted left turn (P+PLT) phasing. In this case the calculation will also depend on the lead-lead/lag-lag or lead-lag configurations. For this configuration, four rules define possible critical paths through a phase sequence. These rules utilize Exhibit 13- 6 through Exhibit 13- 9 and are summarized in Exhibit 13- 10.

When there is P+PLT phasing with a lead-lead or lag-lag configuration, the v/s of protected lefts and permitted lefts in a direction should be summed and compared as show in Exhibit 13-8 below. Drawing a ring and barrier diagram to illustrate leading or lagging protected left and its protected left, see Ring 1 or 2 of the first Barrier in Example 13- 3. Note that there is only one unit of lost time for this direction.

Exhibit 13- 8 Protected-Permitted Lead-Lead Left Turn Phasing Flow Ratio Selection



When there is P+PLT phasing with a lead-lag configuration, the v/s needs to be summed from the leading and lagging left and the highest, controlling, permitted left as shown in Exhibit 13- 9. First, sum the v/s from both protected left leading and lagging phases. Second, identify which through phase has the highest permitted left turn v/s ratio. Lastly, add the permitted left v/s that corresponds to the identified highest v/s through phase (i.e. moves in the same direction) from the second step to the protected leading and lagging v/s sum from the first step. Make sure that the through phase v/s is not accidentally used. It is important to note that there are two units of lost time used for this direction (from the leading and lagging left turn portions).

Exhibit 13- 9 Protected-Permitted Lead-Lag Left Turn Phasing Flow Ratio Selection

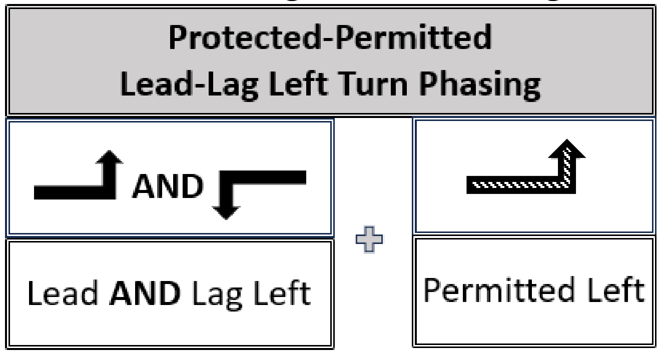


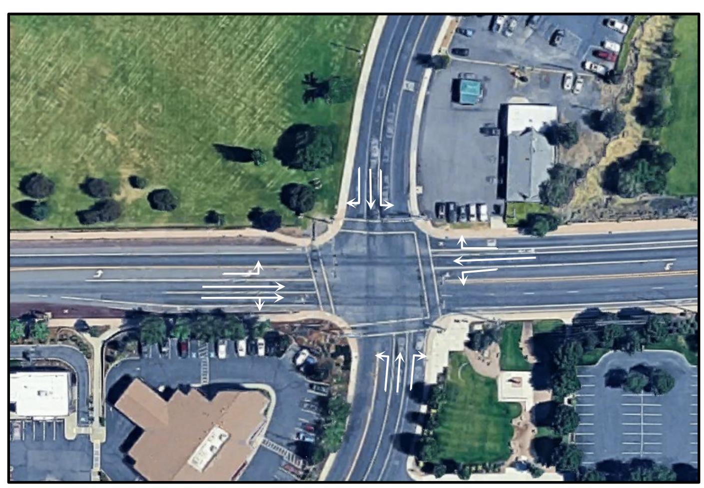
Exhibit 13- 10 summarizes what phase combinations and their applicable flow rates should be considered when selecting a critical path. The phase combination with the highest flow ratio are the critical phases, see Example 13- 3.

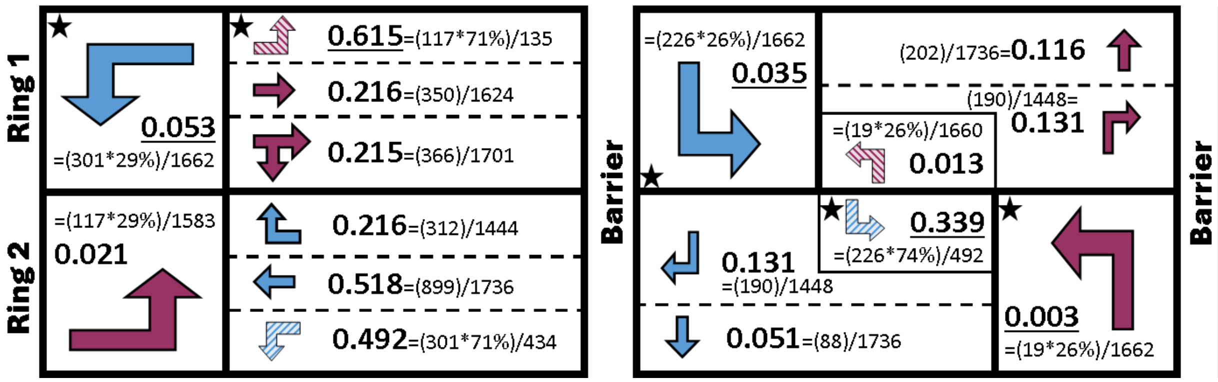
Exhibit 13- 10 Summary for Critical Path Selection

Rule	Applicable Scenarios	Phases for Flow Ratio Calculation	Exhibit/s
1	All	Phases associated in Ring 1 phase sequence	Exhibit 13- 6 and Exhibit 13- 7
2	All	Phases associated with Ring 2 phase sequence	
3	P+PLT (Lead/Lead or Lag/Lag)	Protected Left (Max Total Left Turn A/B) + Permitted Left (Max Total Left Turn A/B)	Exhibit 13- 8
4	P+PLT Lefts (Lead/Lag)	Protected Left (A) + Max Permitted Left (A/B) + Protected Left (B)	Exhibit 13- 9

Example 13- 3 Determining Critical Phases and Cycle Flow Ratio

This example evaluates the urban 4-way signalized intersection of OR216 and SW Rimrock Way in Redmond, OR that is pictured to the right. Immediately north of this intersection is a high school. Three of the four approaches have an exclusive left turn, through, and right turn lane. The west approach has an exclusive left turn and through lane, and a shared through-right lane. Both the E-W and N-S phase pairs have protected-permitted lefts, lead-lead and lead-lag respectively.





★=*Critical Phase*

The phase diagram above represents this intersection and includes each phase's flow ratio and its calculation. Flow ratios for each phase are calculated by dividing a lane group's volume by saturation flow of the analyzed period, typically peak hour. Note that the P+PLT volumes for each direction are proportions of a total left turn volume in a direction. For this example, the proportions are based on "green time" for the movement as show in the table below.

WB Left Movement	Total Vol.	Green Time	Total Time (sec)	LT Ratio	Adj. Volume	Sat. Flow	Flow Ratio
Protected	301	20 sec	70 *(=20+50)*	~29% *(=20/70)*	87 *(=301*29%)*	1662	0.053 *(=87/1662)*
Permitted		50 sec		~71% *(=50/70)*	214 *(=301*71%)*	434	0.492 *(=214/434)*

Next, phase pair flow ratios are summed according to the four rules in Exhibit 13- 10 as tabled below.

Rule #	1st Barrier: E-W	2nd Barrier: N-S
1 (Ring 1)	**<u>0.668</u> = 0.053+0.615** *> (0.053+ 0.216)* *> (0.053+0.215)*	**0.166 = 0.035+0.131** > (0.035+*0.116)*
2 (Ring 2)	**0.539 = 0.021+0.518** *> (0.021+0.492)* *> (0.021+0.216)*	**0.134 = 0.131+0.003** *> (0.051+0.003)*
3 P+PLT (Lead/Lead or Lag/Lag)	**0.636 = (0.021+0.615)** > (0.053+0.492)	n/a
4 P+PLT (Lead/Lag)	n/a	**<u>0.377</u> = (0.035+0.339+0.003)** > (0.035+0.013+0.003

The maximum flow ratio for each barrier is identified (underlined in the table above). The phases associated with the maximum flows are critical phases.

Finally, the cycle flow ratio is the summation critical phases flow ratios (**1.045** = 0.668+0.377)

Calculation Methods

There is a critical intersection v/c calculation tool available on the Technical Tools webpage under the Signalized Intersections dropdown box to assist with Synchro and SIDRA-based analyses. The critical intersection v/c can also be calculated with available intersection analysis tools such as Vistro, Synchro and SIDRA.

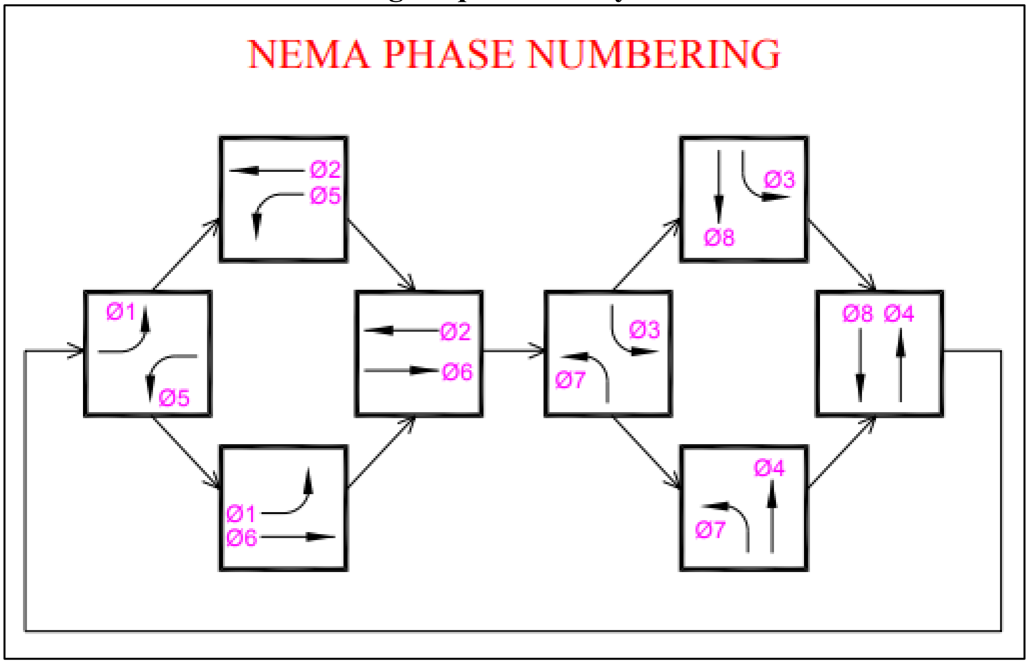
Vistro

The critical intersection v/c ratio is calculated automatically and reported out. Not requiring separate calculation of this value is one of the advantages of using Vistro, particularly where several intersections and/or alternatives are involved. Example 13- 4 illustrates the critical v/c calculation in Vistro.

Synchro

The critical intersection v/c ratio is not provided and must be post-processed. To accomplish this, the most up to date HCM edition report should be used. The HCM 2010 and later methodologies in Synchro expect strict application of NEMA (National Electrical Manufacturers Association) phasing (see Exhibit 13- 11). NEMA phasing requires each phase to have a unique phase number, even if they run at the same time. Odd numbers are used to designate the protected left turn phases while even numbers are used to designate the through phases. A maximum of four left turn phases and four through phases can be designated using NEMA phasing. Numbers 1 and 5 are used to designate the main street left turn phases while Numbers 2 and 6 are used to designate the main street through phases. Phases 1 and 6 are located on the same approach while Phases 2 and 5 are located on the opposite approach. Numbers 3 and 7 are used to designate the cross street left turn phases while Numbers 4 and 8 are used to designate the cross-street through phases. Phases 3 and 8 are located on the same approach while Phases 4 and 7 are located on the opposite approach. Note that for split phasing the through movement phase number needs to be used to allow the Synchro reports to print out.

Exhibit 13- 11 NEMA Phasing Required for Synchro



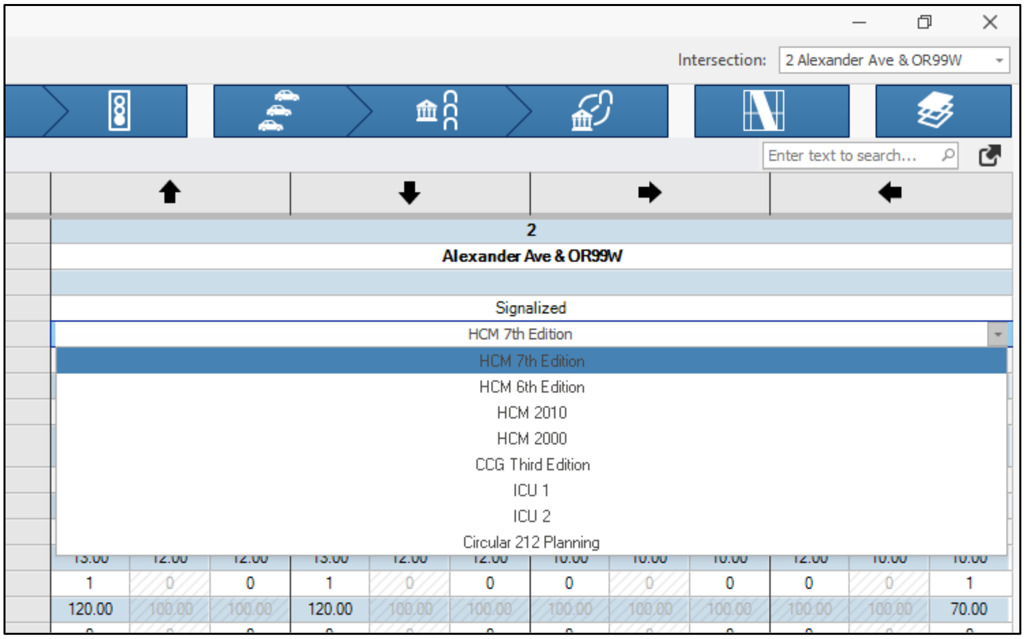
Depending on the signal phasing and the intersection geometry, it may be necessary to create a "workaround". This is described in detail below. Then according to the signal type, using the guidance provided in the discussion above the critical flow ratios can be calculated manually and the critical movements may be identified. The critical intersection v/c ratio can then be calculated using the HCM equation. The procedure to post-process Synchro HCM 2010 and later output is illustrated in Example 13- 5 and Example 13- 6.

<u>SIDRA</u>

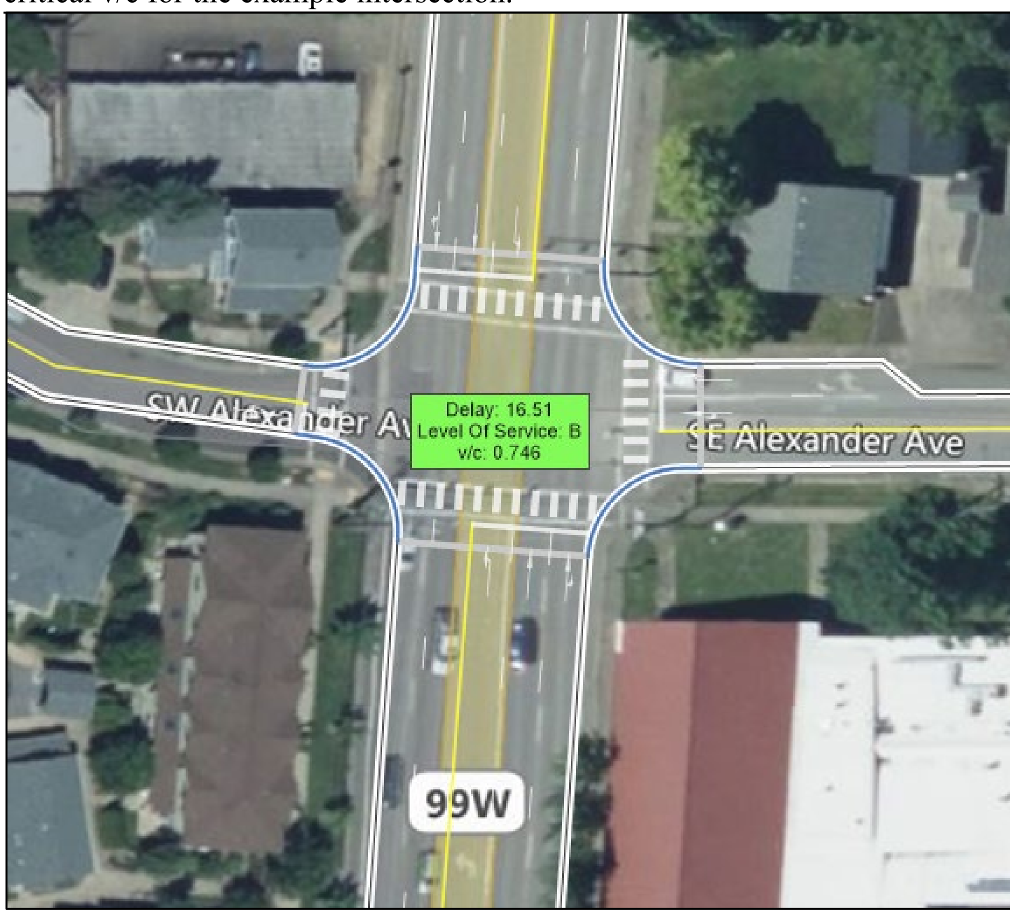
The critical intersection v/c ratio is not provided and must be post-processed. Flow ratios can be calculated using report outputs and critical movements identified. The signal type guidance provided in the discussion above will need to be used to identify critical flow ratios. Then the critical v/c can be calculated using the HCM equation. The procedure to post-process critical intersection v/c ratio from SIDRA output is illustrated in Example 13- 7.

Example 13- 4 Calculating Critical Intersections v/c Ratio in Vistro

As stated above, Vistro directly provides the signalized intersection critical v/c ratio. Note that several different analysis methods may be chosen and HCM 7th Edition should be used as it is the most current. On the north and south legs of the intersection lead-lag left turn phasing is coded in this example (northbound lead; southbound lag) for consistency with the Synchro and Sidra examples. However, for optimization purposes both orientations should be checked (southbound lead; northbound lag) because one may perform better than the other.



After the intersection geometry, volume, signalization, and other pertinent data have been entered into Vistro, the v/c can be displayed by clicking on the "Show Intersection Traffic Conditions" button on the left side of the screen. The figure below shows the delay, LOS, and critical v/c for the example intersection.



Synchro is the only tool that requires two examples to explain the critical v/c calculation. As stated previously, the calculation should be performed using output from the most current HCM Report to be applying the most up-to-date methodology. However, the Synchro HCM 2010 and later methodologies have some limitations in that fully compliant NEMA phasing is required. In practice this means it does not support custom phasing schemes or a protected-permitted left turn from a shared lane; a left turn bay is required. In some project analyses there will be intersections requiring analysis that do not match these criteria. In this situation a "workaround" will be required to calculate the critical v/c. Example 13- 5 will analyze the intersection with geometry consistent with the Vistro and SIDRA examples, uses split phasing, and incorporates the necessary "workaround." Example 13- 6 adds a left turn bay and demonstrates a more straightforward use of the HCM (2010 and later) Report.

Example 13- 5 Calculating Critical Intersection v/c Ratio in Synchro with NEMA Phasing Adjustments

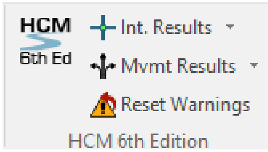
This example assumes that the signalized intersection has protected left turn lead-lag signal phasing on the north and south approaches and split phasing on the east and west approaches. However, it is recommended to only use the HCM 6th /7th Report to identify the lane group flow rates and the saturation flow rates and this report expects NEMA phasing and does not tolerate split-phasing left turns. NEMA phasing requires a unique phase number for each of the four left turn and four through movements.

If the phasing shown below for the east and westbound directions below are used, the *"HCM 6th (or 7th) Edition methodology expects strict NEMA phasing"* error message will be displayed when viewing the HCM 6th /7th Edition Report.

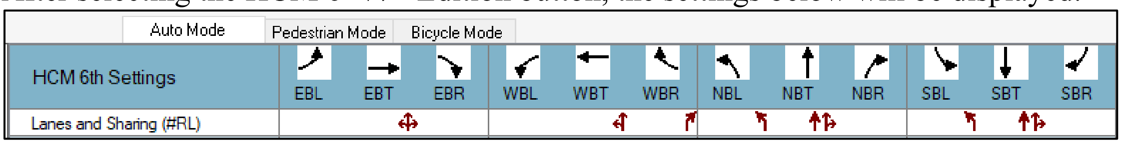
TIMING SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Future Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Turn Type	Split	—	—	Split	—	Prot	Prot	—	—	Prot	—	—
Protected Phases	3	3	—	4	4	4	1	6	—	5	2	—
Permitted Phases			—						—			—
Permitted Flashing Yellow	—	—	—	—	—	—	—	—	—	—	—	—
Detector Phases	3	3	—	4	4	4	1	6	—	5	2	—
Switch Phase	0	0	—	0	0	0	0	0	—	0	0	—
Leading Detector (ft)	—	78	—	—	78	78	78	183	—	78	183	—
Trailing Detector (ft)	—	2	—	—	2	2	2	177	—	2	177	—
Minimum Initial (s)	3.0	3.0	—	5.0	5.0	5.0	3.0	10.0	—	3.0	10.0	—
Minimum Split (s)	32.5	32.5	—	33.5	33.5	33.5	13.0	27.0	—	13.0	26.0	—
Total Split (s)	32.5	32.5	—	33.5	33.5	33.5	13.0	37.0	—	13.0	37.0	—
Yellow Time (s)	4.0	4.0	—	4.0	4.0	4.0	3.5	4.0	—	3.5	4.0	—
All-Red Time (s)	0.5	0.5	—	0.5	0.5	0.5	0.5	1.0	—	0.5	1.0	—
Lost Time Adjust (s)	—	0.0	—	—	0.0	0.0	0.0	0.0	—	0.0	0.0	—
Lagging Phase?	☑	☑	—	☐	☐	☐	☐	☐	—	☑	☑	—
Allow Lead/Lag Optimize?	☑	☑	—	☑	☑	☑	☑	☑	—	☑	☑	—

The following steps will adjust the existing phasing to NEMA phasing:

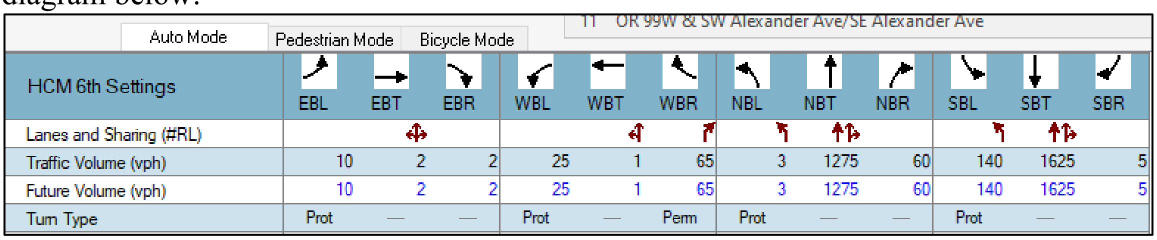
1. From the map view, click on the desired intersection and select the HCM 6th /7th Edition Settings button on the Home tab.



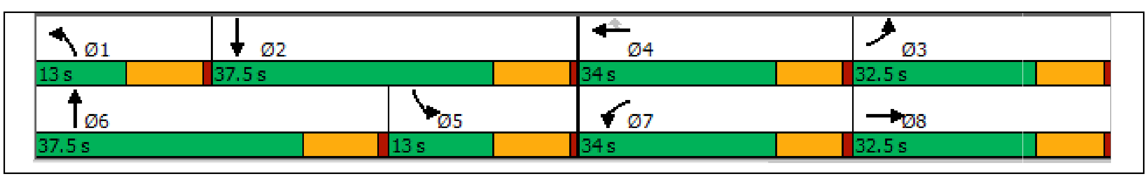
2. After selecting the HCM 6th /7th Edition button, the settings below will be displayed.



3. In the field, the example intersection has a shared eastbound left-through-right and a shared westbound through-left. This does not meet the NEMA phasing requirements. The solution is to assign a unique phase to all left and through movements even if they run concurrently. So, the amended eastbound and westbound phasing will look like the diagram below:



HCM 6th Settings	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Future Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Turn Type	Prot	—	—	Prot	—	Perm	Prot	—	—	Prot	—	—



Note that in some instances there is a much more straightforward fix to meet the NEMA phasing requirement (although there will be times that custom phasing schemes will require the workaround described). In this specific situation a quicker fix is to change the label on Phase 3 to Phase 8 to align with the phasing shown in Exhibit 13- 11. For split phasing use the through movement phase number to allow the Synchro reports to print out. ***The results produced are exactly the same.***

It is important to note that the v/s calculation is based on “Lane Group” values and not exclusive “Lane” values. This becomes an important distinction when there are multiple lane groups in a movement. This occurs when shared through-turn lanes are present. This is seen in the Synchro report shown below for the northbound through and the southbound through lane group movements (circled in red).

The through movement includes two lane groups:

1. Through-right lane
2. Through lane

In the case of multiple lane groups in a movement, the “Group Volume” in vehicles per hour (“Grp Volume(v), veh/h” row in report) should be used for the v/s calculation. The higher lane group v/s for the movement between the through and the through-right should be used for the calculation. This is where the Synchro report provides the required lane group value.

HCM 6th Signalized Intersection Summary
11: OR 99W & SW Alexander Ave/SE Alexander Ave 08/24/2023

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (veh/h)	10	2	2	25	1	65	3	1275	60	140	1625	5
Future Volume (veh/h)	10	2	2	25	1	65	3	1275	60	140	1625	5
Initial Q (Qb), veh	0	0	0	0	0	0	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00		0.94	1.00		1.00	1.00		0.99	1.00		0.99
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach		No			No			No			No	
Adj Sat Flow, veh/h/ln	1900	1900	1900	1900	1900	1900	1976	1826	1841	1945	1856	1900
Adj Flow Rate, veh/h	24 +	5 +	5	35 +	1	92	3	1401	66	156	1806	6
Peak Hour Factor	0.41	0.41	0.41	0.71	0.71	0.71	0.91	0.91	0.91	0.90	0.90	0.90
Percent Heavy Veh, %	0	0	0	0	0	0	0	5	4	2	3	0
Cap, veh/h	0	67	67	0	151	127	21	2038	96	217	2569	9
Arrive On Green	0.00	0.08	0.08	0.00	0.08	0.08	0.01	0.59	0.58	0.12	0.69	0.69
Sat Flow, veh/h	0	844	844	0	1900	1605	1882	3459	163	1853	3696	12
Grp Volume(v), veh/h	0	0	10	0	1	92	3	738	729	156	906	906
Grp Sat Flow(s),veh/h/ln	0	0	1688	0	1900	1605	1882	1826	1795	1853	1856	1853
Q Serve(g_s), s	0.0	0.0	0.3	0.0	0.0	3.1	0.1	15.6	15.7	4.5	16.3	16.3
Cycle Q Clear(g_c), s	0.0	0.0	0.3	0.0	0.0	3.1	0.1	15.6	15.7	4.5	16.3	16.3
Prop In Lane	0.00		0.50	0.00		1.00	1.00		0.09	1.00		0.01
Lane Grp Cap(c), veh/h	0	0	134	0	151	127	21	1076	1058	217	1289	1288
V/C Ratio(X)	0.00	0.00	0.07	0.00	0.01	0.72	0.14	0.69	0.69	0.72	0.70	0.70
Avail Cap(c_a), veh/h	0	0	859	0	1662	1404	302	1076	1058	298	1289	1288
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Upstream Filter(I)	0.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	0.0	0.0	23.9	0.0	23.7	25.2	27.4	7.9	8.0	23.8	5.1	5.1
Incr Delay (d2), s/veh	0.0	0.0	0.2	0.0	0.0	5.6	2.2	3.6	3.7	4.1	3.2	3.2
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(50%),veh/ln	0.0	0.0	0.1	0.0	0.0	1.3	0.0	5.1	5.1	2.1	4.0	4.1
Unsig. Movement Delay, s/veh												
LnGrp Delay(d),s/veh	0.0	0.0	24.1	0.0	23.8	30.8	29.6	11.5	11.6	28.0	8.3	8.3
LnGrp LOS	A	A	C	A	C	C	C	B	B	C	A	A
Approach Vol, veh/h		10			93			1470			1968	
Approach Delay, s/veh		24.1			30.7			11.6			9.9	
Approach LOS		C			C			B			A	

Timer - Assigned Phs	1	2	3	4	5	6	7	8
Phs Duration (G+Y+Rc), s	4.6	42.9	0.0	8.4	10.6	37.0	0.0	8.4
Change Period (Y+Rc), s	4.5	4.5	4.0	4.0	4.5	4.5	4.0	4.0
Max Green Setting (Gmax), s	8.5	32.5	9.0	49.0	8.5	32.5	29.5	28.5
Max Q Clear Time (g_c+I1), s	2.1	18.3	0.0	5.1	6.5	17.7	0.0	2.3
Green Ext Time (p_c), s	0.0	13.6	0.0	0.4	0.1	13.1	0.0	0.0

Intersection Summary	
HCM 6th Ctrl Delay	11.2
HCM 6th LOS	B

Notes

User approved changes to right turn type.

Next, the flow ratios need to be calculated for all movements. The guidance at the beginning of this section should be used according to the phasing type to determine the correct combination of highest flow ratios. In this example there is protected lead-lag left turn phasing on the northbound and southbound approach (follow Exhibit 13- 7). Also recall that because there are four phases, four v/s flow ratios will be used. As described previously, the movements with the highest v/s flow ratio should be used; either

1. northbound-left or southbound left, and
2. northbound through or southbound through, or
3. northbound thought-right or southbound through-right.

In the northbound direction, the northbound shared through-right lane group has the higher v/s over the through lane group. In the southbound direction, the southbound shared through-right lane group has the higher v/s over the southbound through lane group. The table below can be created to help with this determination using the values shown in the Synchro report above.

Road Name	Approach	Lane Group	Lane Group Flow (vph)	Saturation Flow Rate (vph)	v/s Flow Ratio	Use?
OR 99W	NB	Left	3	1882	0.002	x
		Through	738	1826	0.404	
		Shared Thru-Right	729	1795	0.406	
OR 99W	SB	Left	156	1853	0.084	
		Through	906	1856	0.488	
		Shared Thru-Right	906	1853	0.489	x

For the through movements the two-lane groups in each direction were compared to identify the higher v/s (through or shared through-right). In this example the shared through-right lane group was higher in both directions. Then the higher of these two values was used in the calculation as shown in bold below.

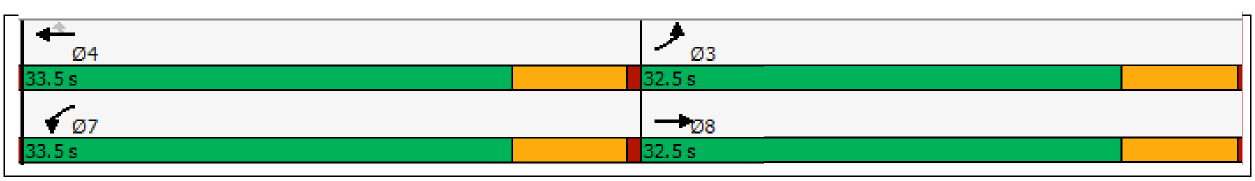
For protected lead-lag phasing from Exhibit 13- 7. Only Rules 1 and 2 of Exhibit 13- 10 are applicable and should be compared.

Rule 1) NBL + SBTR = 0.002 + 0.489 = 0.491
Rule 2) SBL + NBTR = 0.084 + 0.406 = 0.490

The NBL+ SBTR path flow ratio should be used in the calculation (0.491>0.490).

Next the eastbound and westbound movements need to be evaluated. Here there is split phasing. Following the guidance presented above, there are three steps:

1. Each through approach is separate (eastbound + westbound).
2. Check for controlling movements between through and right lane groups.



3. Flow ratios (v/s) are calculated for each movement group by dividing the adjusted flow rate by the saturated flow rate as depicted in the table below.

Road Name	Approach	Lane Group	Lane Group Flow (vph)	Saturation Flow Rate (vph)	v/s Flow Ratio	Use?
Alexander	EB	Shared Left-Thru-Right	34	1688	0.020	x
Alexander	WB	Shared Left-Thru	36	1900	0.019	
		Right	92	1605	0.057	x

There is only one flow ratio for the eastbound movement, so by default, this one is used. For the westbound movement the highest flow ratio between the through and the right movements is chosen which is for the right turn. (0.057>0.019)

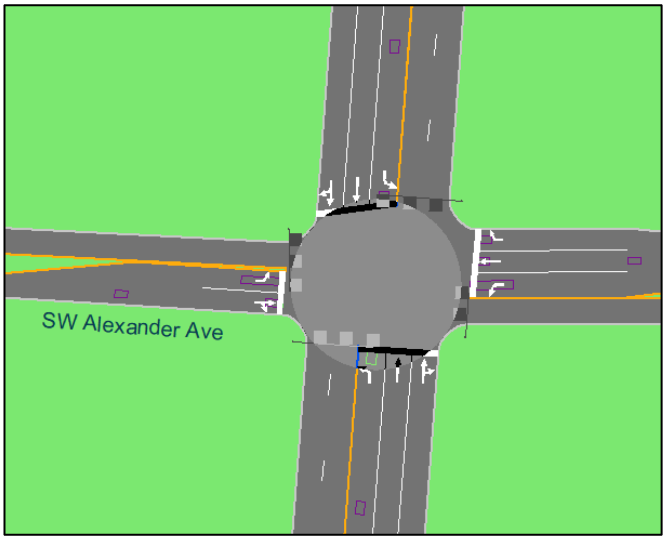
The sum of all critical movement flow ratios is then calculated: 0.002 + 0.489 + 0.020 + 0.057 = 0.568

Cycle length = 116 sec
Lost time per phase = 4 sec
Total Lost time = 16 sec

The critical intersection v/c ratio is then calculated using the HCM equation:
Xc = Sum of critical flow ratios * C/(C-L) = 0.568 * 116/ (116-16) = **0.66**

Example 13- 6 Calculating Critical Intersection v/c Ratio in Synchro

This example uses the same intersection as the previous example but adds eastbound left and westbound left turn bays as shown in the diagram below. Therefore, no modifications to the phasing are necessary to meet the NEMA phasing requirements unlike Example 13- 5.

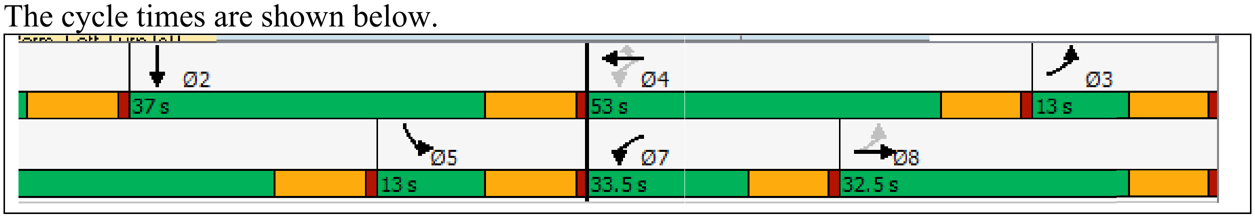


The eastbound and westbound protected-permitted left turn phasing can be coded directly as shown below.

Auto Mode | Pedestrian Mode | Bicycle Mode

HCM 6th Settings	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Future Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Turn Type	pm+pt	—	—	pm+pt	—	Perm	Prot	—	—	Prot	—	—
Protected Phases	3	8	—	7	4		1	6	—	5	2	—
Permitted Phases	8		—	4		4			—			—
Lagging Phase?	☑	☑	—	☐	☐	☐	☐	☐	—	☑	☑	—

The cycle times are shown below.



Next the HCM 6th /7th Edition Report should be created to determine the lane group flow and the saturation flow rate values which are necessary for the critical v/c calculation.

HCM 6th Signalized Intersection Summary
11: OR 99W & SW Alexander Ave/SE Alexander Ave 08/29/2023

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (veh/h)	10	2	2	25	1	65	3	1275	60	140	1625	5
Future Volume (veh/h)	10	2	2	25	1	65	3	1275	60	140	1625	5
Initial Q (Qb), veh	0	0	0	0	0	0	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	0.89		0.94	1.00		1.00	1.00		0.99	1.00		0.99
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach		No			No			No			No	
Adj Sat Flow, veh/h/ln	1900	1900	1900	1900	1900	1900	1976	1826	1841	1945	1856	1900
Adj Flow Rate, veh/h	24	5	5	35	1	92	3	1401	66	156	1806	6
Peak Hour Factor	0.41	0.41	0.41	0.71	0.71	0.71	0.91	0.91	0.91	0.90	0.90	0.90
Percent Heavy Veh, %	0	0	0	0	0	0	0	5	4	2	3	0
Cap, veh/h	131	59	59	145	147	124	16	2068	97	203	2584	9
Arrive On Green	0.03	0.07	0.07	0.03	0.08	0.08	0.01	0.60	0.59	0.11	0.70	0.69
Sat Flow, veh/h	1810	840	840	1810	1900	1604	1882	[illegible]	[illegible]	1853	[illegible]	[illegible]
Grp Volume(v), veh/h	24	0	10	35	1	92	3	738	729	156	906	906
Grp Sat Flow(s),veh/h/ln	1810	0	1681	1810	1900	1604	1882	1826	1795	1853	1856	1853
Q Serve(g_s), s	0.0	0.0	0.5	1.6	0.0	4.7	0.1	23.0	23.2	6.9	24.3	24.3
Cycle Q Clear(g_c), s	0.0	0.0	0.5	1.6	0.0	4.7	0.1	23.0	23.2	6.9	24.3	24.3
Prop In Lane	1.00		0.50	1.00		1.00	1.00		0.09	1.00		0.01
Lane Grp Cap(c), veh/h	131	0	117	145	147	124	16	1092	1073	203	1297	1296
V/C Ratio(X)	0.18	0.00	0.09	0.24	0.01	0.74	0.19	0.68	0.68	0.77	0.70	0.70
Avail Cap(c_a), veh/h	278	0	587	278	664	560	201	1092	1073	241	1297	1296
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Upstream Filter(I)	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	40.1	0.0	36.8	38.6	36.0	38.1	41.6	11.5	11.5	36.6	7.5	7.5
Incr Delay (d2), s/veh	0.5	0.0	0.3	0.6	0.0	6.2	4.3	3.4	3.5	10.8	3.1	3.2
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(50%),veh/ln	0.5	0.0	0.2	0.7	0.0	2.1	0.1	8.9	8.8	3.6	8.2	8.2
Unsig. Movement Delay, s/veh												
LnGrp Delay(d),s/veh	40.6	0.0	37.1	39.2	36.0	44.4	45.9	14.8	15.0	47.4	10.6	10.6
LnGrp LOS	D	A	D	D	D	D	D	B	B	D	B	B
Approach Vol, veh/h		34			128			1470			1968	
Approach Delay, s/veh		39.6			42.9			15.0			13.5	
Approach LOS		D			D			B			B	

Timer - Assigned Phs	1	2	3	4	5	6	7	8
Phs Duration (G+Y+Rc), s	4.7	63.1	6.2	10.6	13.3	54.5	6.8	9.9
Change Period (Y+Rc), s	4.5	4.5	4.0	4.0	4.5	4.5	4.0	4.0
Max Green Setting (Gmax), s	8.5	52.0	9.0	29.5	10.5	50.0	9.0	29.5
Max Q Clear Time (g_c+I1), s	2.1	26.3	2.0	6.7	8.9	25.2	3.6	2.5
Green Ext Time (p_c), s	0.0	24.0	0.0	0.3	0.1	20.9	0.0	0.0

Intersection Summary	
HCM 6th Ctrl Delay	15.4
HCM 6th LOS	B

Notes

User approved changes to right turn type.

Follow the guidance above to walk through the phases and determine the critical movements. The northbound/southbound pair have protected lefts in a lead-lag phasing arrangement. Because there are two phases in the north and south directions there will be two flow ratios used in the calculation which is the highest combination of the northbound left with the southbound through or the southbound left and the northbound through.

Flow ratios (v/s) are calculated for each movement group by dividing the group flow rate by the saturated flow rate as depicted in the table below. The northbound left and southbound left are protected lead-lag phasing and Exhibit 13- 7 should be used as a guide. Recalling from the guidance above that when there is protected lead-lag phasing the higher combination of the northbound left and the southbound through or the southbound left and the northbound through v/s ratio should be chosen. However, in this example, the northbound and southbound through movements each consist of a through and a through-right lane group. Each lane group must be considered and then the highest v/s chosen. In this case, the shared through right lane groups in both directions have a higher v/s over the through lane group.

Road Name	Approach	Lane Group	Lane Group Flow (vph)	Saturation Flow Rate (vph)	v/s Flow Ratio	Use?
OR 99W	NB	Left	3	1882	0.002	x
		Through	738	1826	0.404	
		Shared Thru-Right	729	1795	0.406	
OR 99W	SB	Left	156	1853	0.084	
		Through	906	1856	0.488	
		Shared Thru-Right	906	1853	0.489	x

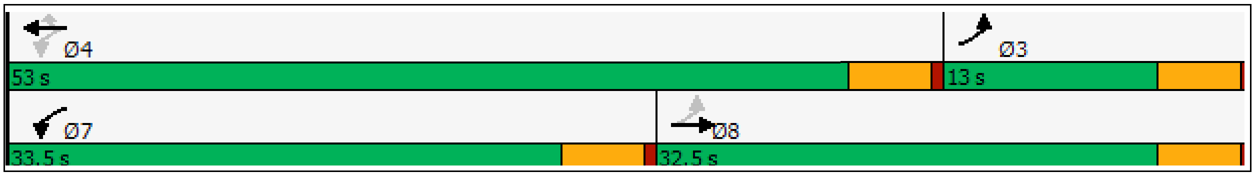
For protected lead-lag phasing, reference Exhibit 13- 7. Only Rules 1 and 2 of Exhibit 13- 10 are applicable and should be compared.

Rule 1) NBL + SBTR = 0.002 + 0.489 = 0.491
Rule 2) SBL + NBTR = 0.084 + 0.406 = 0.490

The NBL+ SBTR path flow ratio should be used in the calculation (0.491>0.490).

Next consider the eastbound and westbound movements that have lead-lag protected-permitted left phasing. Follow the guidance presented above, then there are three additional steps to evaluate Exhibit 13- 10 Rule 4:

i. Identify highest v/s flow ratio of permitted lefts.
ii. Sum the flow ratios of the protected leading and lagging lefts, and the permitted left previously identified, see Exhibit 13- 9.
    a. Note: HCM 2000 Report is needed to isolate saturation flow rates for the protected and permitted lefts.



Using the phasing diagram shown above, the westbound protected left is leading, and the eastbound protected left is lagging. There is not an explicit way to split out the protected and the permitted portions of the left turn volumes. Therefore, the analyst will need to create a proportion based on the cycle time as this is the best proxy available. The phase diagram can be used to create a table such as the one below. A ratio is created for each movement by dividing the protected or permitted portion of the time by the total phase time. This ratio can then be applied to the adjusted flow rate (from the HCM 6th /7th Edition Report) to split the volume into the protected and the permitted portions.

	Left Turn Time (sec)			Left Turn Ratios		Left Turn Flows (vph)		
Movement	**Total Phase Time**	**Protected**	**Permitted**	**Protected**	**Permitted**	**Total Left**	**Protected**	**Permitted**
Eastbound	32.5	13	19.5	0.40	0.60	24	**10**	**14**
Westbound	53	33.5	19.5	0.63	0.37	35	**22**	**13**

The other element of the flow ratio calculation is the Saturated Flow Rate. The HCM 6th /7th Edition Report does not provide this separately for the protected and the permitted portions. The HCM 2000 Report will need to be created to get these values which can be seen boxed in red below (*note that this is the only value that the HCM 2000 Report should be used for*).

With the HCM reports, the elements necessary for the critical intersection v/c calculation have been created and can be seen in the next table. The four rules associated with Exhibit 13- 10 will then be considered as follows:

Rule 1 A) WB thru and EB protected left,
Rule 1 B) WB right and EB protected left, and
Rule 2) WB protected left and EB shared through-right movements.
Rule 3) n/a
Rule 4 A) EB protected left, WB protected left, and EB permitted left
Rule 4 B) EB protected left, WB protected left, and WB permitted left

HCM Signalized Intersection Capacity Analysis
11: OR 99W & SW Alexander Ave/SE Alexander Ave 08/31/2023

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Future Volume (vph)	10	2	2	25	1	65	3	1275	60	140	1625	5
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	12	10	10	13	12	12	13	12	12
Total Lost time (s)	4.0	4.0		4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Lane Util. Factor	1.00	1.00		1.00	1.00	1.00	1.00	*1.00		1.00	*1.00	
Frpb, ped/bikes	1.00	0.99		1.00	1.00	0.99	1.00	1.00		1.00	1.00	
Flpb, ped/bikes	1.00	1.00		1.00	1.00	1.00	1.00	1.00		1.00	1.00	
Frt	1.00	0.93		1.00	1.00	0.85	1.00	0.99		1.00	1.00	
Flt Protected	0.95	1.00		0.95	1.00	1.00	0.95	1.00		0.95	1.00	
Satd. Flow (prot)	1685	1621		1805	1773	1488	1865	3591		1829	3687	
Flt Permitted	1.00	1.00		1.00	1.00	1.00	0.95	1.00		0.95	1.00	
Satd. Flow (perm)	1773	1621		1900	1773	1488	1865	3591		1829	3687	
Peak-hour factor, PHF	0.41	0.41	0.41	0.71	0.71	0.71	0.91	0.91	0.91	0.90	0.90	0.90
Adj. Flow (vph)	24	5	5	35	1	92	3	1401	66	156	1806	6
RTOR Reduction (vph)	0	5	0	0	0	86	0	2	0	0	0	0
Lane Group Flow (vph)	24	5	0	35	1	6	3	1465	0	156	1812	0
Confl. Peds. (#/hr)			15			1			7			12
Heavy Vehicles (%)	0%	0%	0%	0%	0%	0%	0%	5%	4%	2%	3%	0%
Turn Type	pm+pt	NA		pm+pt	NA	Perm	Prot	NA		Prot	NA	
Protected Phases	3	8		7	4		1	6		5	2	
Permitted Phases	8			4		4						
Actuated Green, G (s)	3.3	3.3		4.6	4.6	4.6	1.0	35.2		12.4	46.6	
Effective Green, g (s)	3.3	3.3		4.6	4.6	4.6	1.5	35.7		12.9	47.1	
Actuated g/C Ratio	0.05	0.05		0.07	0.07	0.07	0.02	0.51		0.18	0.67	
Clearance Time (s)	4.0	4.0		4.0	4.0	4.0	4.5	4.5		4.5	4.5	
Vehicle Extension (s)	2.5	3.0		2.5	2.5	2.5	2.5	4.6		2.5	4.6	
Lane Grp Cap (vph)	82	75		123	115	96	39	1815		334	2459	
v/s Ratio Prot	0.01	0.00		0.01	0.00		0.00	c0.41		0.09	c0.49	
v/s Ratio Perm	c0.01			c0.01		0.00						
v/c Ratio	0.29	0.07		0.28	0.01	0.06	0.08	0.81		0.47	0.74	
Uniform Delay, d1	31.0	32.2		31.5	30.9	31.0	33.9	14.6		25.8	7.7	
Progression Factor	1.00	1.00		1.00	1.00	1.00	1.00	1.00		1.00	1.00	
Incremental Delay, d2	1.4	0.4		0.9	0.0	0.2	0.6	4.0		0.8	2.0	
Delay (s)	32.4	32.6		32.4	30.9	31.2	34.5	18.5		26.5	9.7	
Level of Service	C	C		C	C	C	C	B		C	A	
Approach Delay (s)		32.5			31.5			18.6			11.0	
Approach LOS		C			C			B			B	

Intersection Summary			
HCM 2000 Control Delay	15.0	HCM 2000 Level of Service	B
HCM 2000 Volume to Capacity ratio	0.77		
Actuated Cycle Length (s)	70.6	Sum of lost time (s)	16.0
Intersection Capacity Utilization	72.0%	ICU Level of Service	C
Analysis Period (min)	15		
c Critical Lane Group			

Road Name	Approach	Lane Group	Lane Group Flow (vph)	Saturation Flow Rate (vph)	v/s Flow Ratio	Use?
Alexander	EB	Permitted Left	14	1773	0.008	
		Protected Left	10	1685	0.006	x
		Shared Thru-Right	10	1681	0.006	
Alexander	WB	Permitted Left	13	1900	0.007	
		Protected Left	22	1805	0.012	
		Through	1	1900	0.001	
		Right	92	1604	0.057	x

Flow ratios are calculated for each movement lane group by dividing the adjusted flow rate by the saturated flow rate:

EB Protected Left = 10/1681 = 0.006
WB Protected Left = 22/1805 = 0.012
EB Permitted Left = 14/1773 = 0.008

The flow ratio combinations are then compared to determine the critical phases:

Rule 1 A) 0.001+0.006 = 0.007
Rule 1 B) 0.057+0.006 = **0.063**
Rule 2) 0.012+0.006 = 0.018
Rule 3) n/a
Rule 4 A) 0.006+0.012+0.008 = 0.026
Rule 4 B) 0.006+0.012+0.007 = 0.025

The scenario with westbound right and eastbound protected-left (Rule 1 B) has the highest flow ratio and should be used.

Next, sum of all critical phases flow ratios: 0.002+0.489+0.006 +0.057 = **0.554**

Cycle length = 116 sec
Lost time per phase = 4 sec
Total Lost time = 16 sec

Note that although five flow ratios are used in the calculation, there are still only four phases. So, the total lost time is 16 seconds.

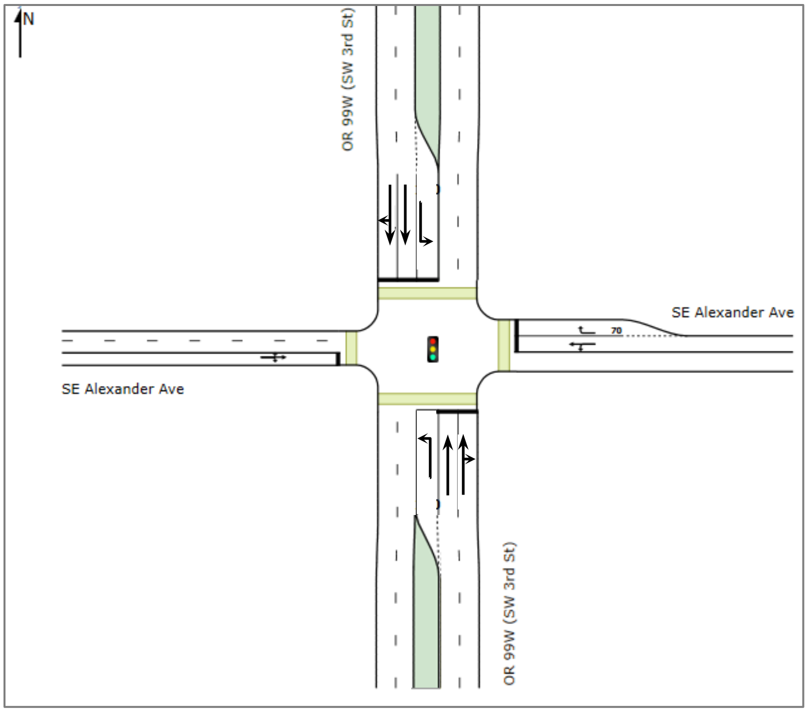
The critical intersection v/c ratio is then calculated using the HCM equation:
Xc = Sum of critical flow ratios * C/(C-L) = 0.517 * 116/ (116-16) = **0.64**

SIDRA is known to create a critical intersection v/c ratio that is more of an outlier than the other tools. The analyst should be aware of this and understand why this is the case.

1. SIDRA is known to use several extensions and additions, such as the throttling of volumes upstream and downstream from the intersection if capacities are exceeded. This will impact the saturated flow rates by reducing them which will cause a higher v/c, but it will also reduce the volume reaching the intersection which will cause a lower v/c. Depending on which effect creates a larger reduction will determine which direction the v/c shifts.
2. SIDRA is correctly "seeing" the existing capacity issues adjacent to the intersection which would limit traffic reaching it. This provides a more realistic result for congested conditions.
3. SIDRA is unique. The User Guide provides the following information: "SIDRA INTERSECTION is compatible with the Highway Capacity Manual. However, unlike other software packages, the HCM Setup in SIDRA INTERSECTION does not claim to be a simple replication of the HCM procedures. Instead, SIDRA INTERSECTION offers various extensions on the capabilities HCM offers."

Example 13- 7 Calculating Critical Intersection v/c Ratio in SIDRA Intersection

This example shows the calculations for the intersection v/c ratio for a four-leg four-phase intersection in SIDRA. The phase rotation is given as protected lead-lag left turn signal phasing on the north and south approaches and permitted split phasing on the east and west approaches. The cycle time is 116 seconds with four seconds of lost time assumed for each phase (for consistency with the other examples). SIDRA has a different optimization routine than the other software and frequently uses internally computed practical cycle time, which was 137 seconds here (vs. user defined cycle time). The signalized intersection layout is shown below.



Calculate the critical flow ratios for each phase using output from the from the “Lane Flow and Capacity Information” report found withing “Detailed Output”. Note that Lane 1 is the left turn lane and Lane 2 is the through-right lane. Earlier versions of SIDRA gave the flow ratios directly, but Version 9.1 will require that they be calculated separately. Flow ratios are calculated by dividing the total arriving flow by the saturation flow accounting for lane blockage. Note that while this example does not have any lane blockage effects, the values in the two saturation flow columns can be substantially different when there are lane blockages.

LANE FLOW AND CAPACITY INFORMATION

Lane No.	Total Arv Flow veh/h	Lane Width ft	Adj. Basic tcu/h	Saturation Flow Rate: W/O Lane Blockage 1st veh/h	Saturation Flow Rate: W/O Lane Blockage 2nd veh/h	Saturation Flow Rate: With Lane Blockage 1st veh/h	Saturation Flow Rate: With Lane Blockage 2nd veh/h	End Cap veh/h	Tot Cap veh/h	Deg. Satn x	Lane Util %
South: OR 99W (SW 3rd St)											
1	3	13.0	1976	1951		1951		53	712	0.005	100
2	737	12.0	1900	1803<		1803<		0	658	1.119	100
3	730	12.0	1900	1780	357	1780	357	0	652	1.119	100
East: SE Alexander Ave											
1	37	12.0	1900	1813		1813		0	132	0.277	100
2	92	10.0	1900	1610	1610	1610	1610	0	1446	0.063	100
North: OR 99W (SW 3rd St)											
1	156	13.0	1976	1473		1473		52	527	0.295	100
2	850	12.0	1900	1632<		1632<		0	596	1.428	100
3	961	12.0	1900	1843	21	1843	21	0	673	1.428	100
West: SE Alexander Ave											
1	34	10.0	1900	599	1481	599	1481	77	102	0.336	100

< Reduced saturation flow due to a short lane effect
Delay and stops experienced by drivers upstream of the short lane entry have been accounted for.

Basic Saturation Flow in this table is adjusted for area type factor, lane width, approach grade, parking manoeuvres and number of buses stopping.
Saturation flow scale (Demand & Sensitivity dialog) applies if specified.

Saturation Flow rates Without (W/O) Lane Blockage are used for signal timing purposes when the signal timing option to exclude downstream lane blockage effects is selected in Network analysis.

The "Saturation Flows" report may also be used. The Saturation Flow Rate in the column furthest to the right is the appropriate value to use as it includes both downstream lane blockage and short lane effects. The values are identical to the "Saturation Flow Rate" report values so either may be used.

SATURATION FLOWS

Site: [OR 99W at SE Alexander (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

OR 99W at SE Alexander
SB Approach dist is from flashing beacon
NB Approach dist is from Viewmont
Site Category: (None)
Signals - Actuated Isolated   Cycle Time = 137 seconds (Site Practical Cycle Time)
This Site is not connected to the Network.

Lane Saturation Flow Rates	Basic Satn Flow [1] tcu/h	CTORS Satn Flow [3]] veh/h	Green Period	Other Model Elements [4] veh/h	Lane Block. [5] veh/h	Short Lane [6] veh/h
South: OR 99W (SW 3rd St)						
Lane 1	1900	1882	1	1951	1951	1951
Lane 2	1900	1810	1	1810	1810	1803[8]
Lane 3	1900	1782	1	1780	1780	1780
			2	357	357	357
East: SE Alexander Ave						
Lane 1	1900	1813	1	1813	1813	1813
Lane 2	1900	1610	1	1610	1610	1610
			2	1610	1610	1610
North: OR 99W (SW 3rd St)						
Lane 1	1900	1845	1	1473	1473	1473
Lane 2	1900	1845	1	1845	1845	1632[8]
Lane 3	1900	1843	1	1843	1843	1843
			2	21	21	21
West: SE Alexander Ave						
Lane 1	1900	1790	1	599	599	599
			2	1481	1481	1481

The guidance provided at the beginning of this section indicates that there will be two v/s flow ratio elements used for the north-south directions. For protected lead-lag phasing reference Exhibit 13- 7. Only Rules 1 and 2 of Exhibit 13- 10 are applicable and should be compared. The values boxed in red in the detailed report shown above can be used to calculate all the flow ratios for the applicable lane groups and create a table like the one shown below.

Road Name	Approach	Lane Group	Lane Group Flow (vph)	Saturation Flow Rate (vph)	v/s Flow Ratio	Use?
OR 99W	NB	Left	3	1951	0.002	x
		Through	737	1803	0.409	
		Shared Thru-Right	730	1780	0.411	
OR 99W	SB	Left	156	1473	0.106	
		Through	850	1632	0.521	
		Thru-Right	961	1843	0.521*	x

* *Note that the southbound v/s appear to be the same, but the through-right is slightly higher when taken out to four decimals as a tie-breaker (0.5214 vs 0.5208).*

Rule 1) NBL + SBTR = 0.002 + 0.521 = 0.523
Rule 2) SBL + NBTR = 0.106 + 0.411 = 0.517

The NB v/s flow ratio should be used in the calculation = **0.523**

For the eastbound-westbound phase, there are two saturation flow rates given for the different green periods (this is a reflection of a varying saturation flow rate caused by turning vehicles or overflow effects from the adjacent turn lane), as detailed in the" Lane Flow and Capacity Information" report shown above. For the calculation, typically the larger saturation flow rate is used. Again, using the "Lane Flow and Capacity Information" provided in the Detailed Report shown above the table below can be created.

Road Name	Approach	Lane Group	Lane Group Flow (vph)	Saturation Flow Rate (vph)	v/s Flow Ratio	Use?
Alexander	EB	Shared Left-Thru-Right	34	1481	0.023	x
Alexander	WB	Shared Left-Thru	37	1813	0.020	
		Right	92	1610	0.057	x

Because this is a split phase, only Exhibit 13- 10 Rule 1 is applicable, and the critical flow ratio can then be calculated:

i. WBR v/s flow ratio = highest of the shared through-right or exclusive right lane group which is determined to be the WBR (0.057>0.020);
ii. These are then summed to obtain the critical pair flow ratio = 0.023 + 0.057 = **0.080**

The critical v/c ratio (X_c) is then calculated by dividing the cycle length by the cycle length minus the lost time per cycle and then multiplying this times the sum of the critical flow ratios for each phase. As stated previously, there are 4 seconds of lost time per phase and a 116 second cycle time was used (not the Site Practical Cycle Time provided by SIDRA). This is a four-phase intersection, so 16 seconds of total lost time is used.

X_c = [C / (C-L)] * (N-S + E-W) = [116s / (116s-16s)] * (0.523 + 0.080) = **0.70**

Important Software Notes

- Comparison of tools may lead to disservice as each tool has different strengths and internal methodologies.
  - Synchro is best used on signalized arterials with standard intersection configurations where progression is important.
  - SIDRA is best used when congestion is evident or where intersections are non-standard or affected by additional modes (i.e. bike signals, bus lanes, etc.).
  - Vistro is best used for comparing multiple scenarios across simpler intersection configurations and where the greatest efficiency is required.

The resulting intersection v/c's are all generally consistent, but Synchro tends to be lower, SIDRA higher, and Vistro in the middle. The overall context of the study area, the questions to be answered, and the desired analysis need should drive the tool choice. Results will be relative within a single tool and may not be consistent when compared to other tools, so the analyst must understand the differences between them.

- SIDRA will always tend to be more of an outlier as it has numerous HCM extensions and a more rigorous congestion methodology, but under congested conditions it may provide results more in line with actual operations. This is because it accounts for decreased traffic flow in congested and saturated conditions. It should be thought of more in the "spirit of" the HCM rather than a strict replication but still retains basic compatibility.

- Vistro is the only one of the three tools that directly provides the signalized intersection critical v/c ratio with no post-processing required, but it does have simpler inputs and is not as flexible as Synchro or SIDRA, so this is a trade-off.
- Synchro expects strict NEMA phasing which may require careful “workarounds”.
- Protected + permitted left turn phasing is a topic of ongoing discussion regarding best practices as current HCM reporting does not include all the necessary outputs. When using Synchro, extra steps are required when calculating v/c ratios in this scenario. However, Vistro calculates the v/c ratio internally and doesn’t require post-processing, negating this issue.

13.4.5 Analysis Procedures Regarding Signal Timing

Capacity analysis of signalized intersections should be performed in accordance with the methods and default parameters contained in this manual. ODOT has established the following criteria for traffic impact studies regarding the timing chosen for the capacity analysis of signalized intersections. ODOT reserves the right to reject any operational improvements that in its judgment would compromise the safety and efficiency of the facility.

Phase Splits

Thirteen seconds is the lowest total split that should be used including yellow and all-red time. Clear documentation of the selected maximum splits for each phase must be provided in the analysis. The total side street splits should not be greater than the highway splits. Except in cases where the analyst is directed otherwise by ODOT staff, the splits are considered optimized when they yield the lowest overall intersection v/c ratio. This optimization should be done for each capacity analysis.

Non-Coordinated Signals

Cycle lengths and phase splits should be optimized to meet an ideal level of service, queuing and/or volume to capacity ratio for a non-coordinated traffic signal intersection. If simulation is going to be needed, existing signal timing will be necessary for the calibration process. For a new signal, the cycle length for the analysis should not exceed 60 seconds for a two-phased traffic signal, 90 seconds for a three-phased traffic signal (e.g., protected highway left turns, and permissive side streets left turns) or 120 seconds for a four or more phased traffic signal. The signal cycle length should cover the pedestrian clearance time for all crosswalks. For information on pedestrian crossings, see ODOT Traffic Signal Policy and Guidelines.

Signals in Coordinated Signal System

At the start of a project, ODOT staff will determine whether the analysts should use the existing signal timings for all analysis scenarios or develop optimized timings for the coordinated system. The existing timings may need to be used to calibrate a simulation model. If the existing timings are to be used in the analysis, Region traffic shall provide timing files, timing sheets or Synchro files of the existing settings. If optimized timings are to be developed, those settings are subject to approval by ODOT, and those conditions become the baseline for all comparisons.

The following settings should be optimized for each analysis scenario when the analyst is asked to use optimum coordination settings.

- Cycle Length
- Phase Length (Splits)
- Phase Sequence (Lead/Lag Left Turns)
- Intersection Offsets

The optimum settings must meet the criteria established in OAR 734-020-0480 as it relates to progression analysis while also attempting to find the lowest v/c ratio for each intersection. This OAR only applies when modifications are proposed to a signal which would affect the settings of the coordination plans. Examples of these modifications are changes in cycle length, decreased green time for mainline, additional phases, longer crosswalks and intersection relocation. For specific software setting requirements refer to Appendix 12/13.

Adaptive Signal Timing

In non-adaptive/responsive control, signalized intersections operate off a set of timing plans that are programmed into the signal controllers. Adaptive Signal Timing (AST) technology allows the signal controller to continuously vary the signal timing (green time or splits) based on detection of real time traffic flows. AST is normally installed as a system with multiple signals in coordination and focuses on progression. AST can better progress traffic when the signal system is under-saturated as compared to set timing plans. When these signals operate under fully saturated or oversaturated conditions the timing can be more consistent since the splits are maxed out. There are different types of AST platforms that are currently available and installed on ODOT facilities and those of local jurisdictions (i.e. SCOOT, SCATS, RHODES, OPAC, Insync, Synchro Green, etc.).

Traditional capacity analysis methods based on the Highway Capacity Manual (e.g. Synchro, SimTraffic, HCS) analyze signalized intersections assuming a set timing scheme and do not model AST behavior. Multiple analysis methods are possible. The simplest method to analyze AST is to assume all intersections are actuated and coordinated, and to optimize the signal timing even for Existing conditions.

Other possible methods include

- Run different scenarios over a full range of cycle lengths and splits and take the average of the results.
- Some adaptive signal controller data can be input directly into Vissim.
- Use Vissim's custom adaptive signal timing

Future Signals

For future signals, left turns should be assumed to have the appropriate phasing (i.e., permitted, protected-permitted or protected only) according to the criteria for left turn treatment contained in the current ODOT Traffic Signal Policy and Guidelines. The Region Traffic Section and the Traffic Section should be consulted any time a new signal is proposed. It should always be considered that while new traffic signals provide a benefit to some users, the capacity of the mainline is typically cut in half by new signal installations and improper or unjustified signals can increase the frequency of rear-end collisions, delays, disobedience of signal indications and the use of less adequate routes.

Signal Timing Sheets

If it is desired to closely match the current traffic operations, the timing parameters installed in the signal controller need to be used in the analysis. The field timing parameters are recorded on the signal timing sheets located in the signal cabinet. Signal timing sheets should be obtained from the Region Traffic office as they generally have the most recent copies from the signal cabinet. Signal timing changes frequently, so the analyst should make sure to have the most recent version. For the analyst, not all the included sheets are necessary, but it is important that all the needed sheets are obtained. The following shows the important sheets (shown in Exhibits 13-13 through Exhibit 13- 19), Sheets 2, 3, 6, 7 and 8. Sheets 4 and 5 are required if multiple timing plans exist) and what to look for on each sheet. The example signal timing sheet used to illustrate this section is the intersection of US 97 (Bend Parkway) and Pinebrook Boulevard in Bend.

<u>Sheet 2 – Phase Rotation Diagram</u>

The phase rotation diagram shows how the signal operates through its cycle. This diagram is needed so the signal is entered correctly into Synchro or another program. For complicated phasing, the diagram is an invaluable source. Exhibit 13- 13 shows a phase rotation diagram for US 97 and Pinebrook Boulevard, which is a two-phase signal. Many timing sheets, especially the electronic ones, are missing the phase rotation diagram. Contact the appropriate Region Traffic section to obtain.

Exhibit 13- 12 Signal Timing Sheet 2

SHEET 2

Date sheet in effect:

Date sheet voided:

Location: Hwy 97 @ Pinebrook

Table Numbers refer to Trafficview & Translink

TABLE 3

Clock, EV and Misc. (C + Key)									
Function	Key	Clock Location C + 3 uses Call / Active Display Sunday = 1							
Year	0								
Month	1								
Date	2								
Day of Week	3								
Hour	4								
Minute	5								
Second	6								
1/10 Second	7								
		Phase Number							
		1	2	3	4	5	6	7	8
	8								
[illegible]	[illegible]								
Handicap Ped	E								

TABLE 3

Preemption Data (E+Key)			
Function	Key	Parameter	Timing
EVA	0	Delay	0
	1	Minimum	1
EVB	2	Delay	0
	3	Minimum	1
EVC	4	Delay	0
	5	Minimum	1
EVD	6	Delay	0
	7	Minimum	1
Overlaps	8	Red Revert	5.0
Railroad	9	Delay	
	A	Minimum	

		Phase Number							
		1	2	3	4	5	6	7	8
RR Clear Ph	B								
RR Permit	C								
RR OL Permit	D								
Nema Hold Ph	E								
	F								

TABLE 6 (also see sheet 6)

Miscellaneous (D + Code)			
Function	Code	Value	Notes
Floating Ped	2E		0 = Off 1 = On (Ph. 7 & 8 Not permitted)
ID Number	2F	061	Range 0 to 253 (1)
Coordination Ped Recalls	3E	1	0 = Recall 1 = No Recall
Rest in WALK	3F		0 = Off 1 = ON
Advance Warning End of Green	4E		Extend time for green after sign turns on (2) (5)
Advance Warning	4F		Delay time for sign after yellow (2) (5)
[illegible]	[illegible]		[illegible] red [illegible] flash
[illegible]	[illegible]		1 = Flash [illegible] Flash Red
NEMA Inputs	66		Non zero value reassigns C1 inputs. (3)
Bus Delay	6D		Delay time before preemption (4)
Bus Timer #1	6E		Extension of max green for phases 2 & 6 (Free operation)
Bus Timer #3	6F		Force off time for Ph 4 & 8 (only in Free operation)
JHK Protocol	76		0 = no 0.1 = yes
JHK Area No. & 1st digit local	7D		Area No. 0 - 7 and Local 001 - 510 (1)
EV minimum timed Start / end of call	7E		0 = at start of call 1 = at end of call
EV On Indicators	7F		0 = Off, 1 = Flash, 5 = solid indication (5)

Notes

(1) JHK ID no. is formed by Area no. (0 to 7) and 3 digit Local no. (001-510). Left most digits entered as x.x in location 7D and rightmost as xx in location 2F

(2) See Sheet 6, Location B+0+E

(3) C1 pins 54, 63, 64, 75, 76, and 77. See sheet 6, Location B+0+D.

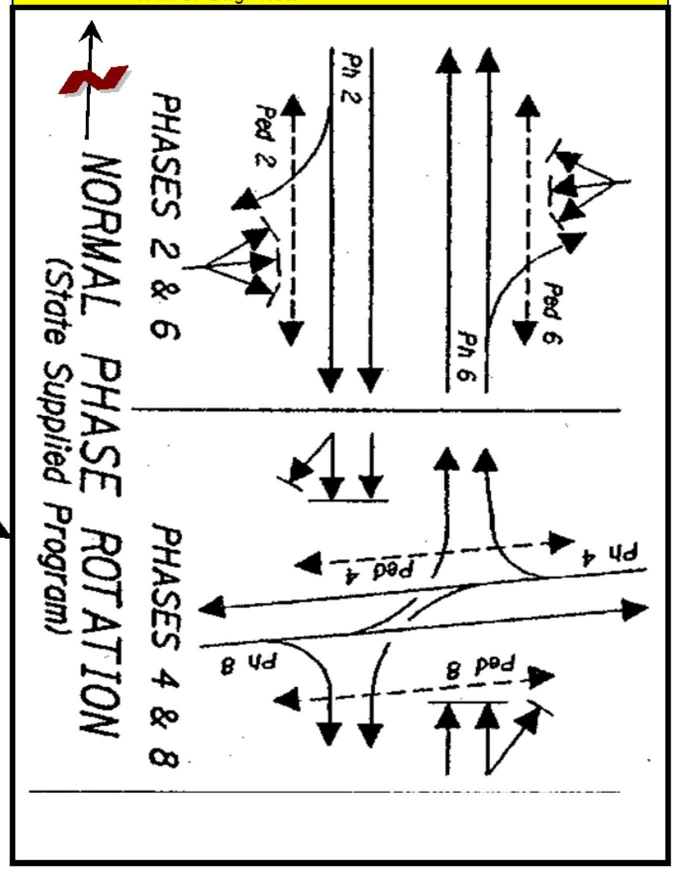
(4) Entering 25.5 in this location is the only way of disabling bus preempt.

(5) Ped yellow outputs, C1-35, 36, 37, and 38 are used by Rt. Turn Overlaps, EV on indicators, TOD/DOW programmable outputs, Fiber Optic sign for RR flash yellow clearance, and Advance Warning sign operation.

Phase Rotation Diagram

Phase Rotation Diagram

T. M. S. Dwg. Nos:



Sheet 3 – Table 1 Phase Functions

Table 1 (Exhibit 13- 14) shows the basic phasing properties and Exhibit 13- 14 shows the pedestrian timings and the advanced actuated phasing properties needed for signalized analysis and simulation programs. Vehicle Recall (Key =0) shows what phases will appear for at least a minimum amount of time in each cycle the signal would return to if there is no demand on the side street. Permitted Phase (Key=4) shows what phases are present at this intersection. Overlap A-D (Key A-D) shows what phases operate together on each of the overlap outputs on the controller. If there are no checked boxes in this section, then there are no overlapping phases, but there may be signal heads displaying outputs from two phases such as the common vertical five-section right-turn signal head.

Sheet 3 – Table 1 Phase Timing

For non-coordinated signals, the cycle length and phase splits can be determined from the Phase Timing portion of Table 1. If multiple timing plans exist, then they will be listed on Sheet 4 and/or Sheet 5. The only values that are needed to determine splits and cycle lengths from this portion of Table 1 are the maximum greens (Key = ph + 0), max 2 greens (Key = ph +1), yellow time (Key = ph + C) and all-red time or red clear (Key = ph + D).

The cycle length of actuated signals will vary from cycle to cycle depending on the vehicle demand. Synchro's phase splits include yellow and all-red, which is different from the maximum green on the timing sheet. Synchro also forces the maximum greens to add up perfectly to the cycle length. Therefore, the maximum cycle length needs to be proportionally adjusted down to match with Synchro's cycle length (the cycle length that is entered into the program). The maximum cycle length can be determined by summing the maximum greens (or max 2 greens if those are used in the analysis hour) and the yellow/all-red for each phase. The max green values on Sheet 3 are just that, i.e., maximum green times. The total maximum split used in Synchro will be the sum of the max green (or max 2 green), yellow and all-red. To convert the Sheet 3 timing into Synchro-compatible timing, the following is done.

1. Add up the Synchro cycle lengths from Sheet 3 by summing the maximum greens.
2. Add the yellow time and all-red time to the cycle length calculated in Step 1 to obtain the maximum cycle length.
3. The Synchro phase lengths are calculated by dividing the green + yellow + all-red time for a phase by the maximum cycle length. This ratio is then multiplied by the Step 1 Synchro cycle length.
4. Repeat for each phase.

The sum of the Synchro phases should add up to the Step 1 cycle length.

Exhibit 13- 13 Signal Timing Sheet 3 – Basic Phase Settings

Da

Vehicle Recall, Permitted Phases & Overlaps

Hwy 97 @ Pinebrook

TABLE 1 Page 0

Phase Functions (0+Key)

Function	Key	1	2	3	4	5	6	7	8
		Phase Number *							
Veh Recall	0		X				X		
Ped Recall	1								
Red Lock	2								
Yellow Lock	3								
Permit Phase	4		X		X		X		X
Ped Phases	5		X		X		X		X
Lead Phases	6	X		X		X		X	
Double Entry	7				X				X
Sequential	8								
Start Green	9		X				X		
OLA=	A								
OLB=	B								
OLC=	C								
OLD=	D								
Exclusive	E								
Sim Gap	F		X				X		

TABLE 2 Page 0

Miscellaneous (C+F+Key)

Function	Key	Value	
Page ID	0	0	Keys 8 through F use Call/Active Display
	1		
	2		
	3		
OLA Red	4		
OLB Red	5		
OLC Red	6		
OLD Red	7		

Function	Key	1	2	3	4	5	6	7	8
		Phase Number							
RT OLE	8								
RT OLF	9								
Red Rest	A								
Max Recall	B								
Flash Green	C								
	D								
Advance WALK	E								
Restrictive Ph	F								

* Shown on Call/Active Display

SHEET 3

TABLE 1 Page 0

Phase Timing (Ph. No. + Key)

Interval	Key	1	2 Southbound Hwy 97	3	4 Westbound Pinebrook	5	6 Northbound Hwy 97	7	8 Eastbound Pinebrook
		Phase Number							
Max Green	0		50		30		50		30
Max2 / HFDW	1		40		35		40		35
Walk	2		5		5		5		5
Flashing DW	3		21		21		22		25
Max Initial	4		20		5		20		5
Min Green	5		10		5		10		
TBR	6		10		5		10		
TTR	7		20		5		20		
Observe Gap	8								
Passage	9		5.2		3.5		5.2		
Min Gap	A		3.2		1.0		3.2		
Add per Act	B		1.5				1.5		
Yellow	C		4.0		4.0		4.0		4.0
Red Clear	D		1.0				1.0		
Red Revert	E		5.0		5.0		5.0		5.0
Walk 2	F								

To observe timing for an individual phase :
Enter C + A + F for Ring A (Phase 1-4) or enter C + B + F for Ring B (Phase 5-8)

Page I.D. 0

Phase Conditions as shown on Free Display

00	Initial Entry	0C	Yellow
02	WALK	0D	Red C
03	Flashing DW	0E	Red R
05	Min Green	11	Gap Out
08	Rest	12	Force Off
09	Passage	14	Max Out
0B	Added Initial	15	Red Revert Timed out

TABLE 2 Page 0

Miscellaneous (9+Key)

Parameter		Key	Value	Notes
Short Pwr Dn		0		Clock Correction Speed up 1 - 9 Slow down 11 - 19
Long Power Dn		1		
Preemption Delay Types	EVA	2		Preemption Delay Types: Hold 1 Latch 2 Both 3 Neither 0
	EVB	3		
	EVC	4		
	EVD	5		
	RR	6		
OLD	Green	E		
	Yellow	F		

Maximum Green and Max 2 Green Times

Sheet 8 indicates when each is in effect.

Keyboard Entries when not in Free Display

A	Advance	D	Column Advance
B	Back	E	Enter and Advance
C	Clear Display	F	Free Display

Yellow and All-red Time

Phase Data Copy
C + x + C + y + D
x From Phase (x cannot be 3 or 8)
y To Phase(s) - up to 3

Exhibit 13- 14 Signal Timing Sheet 3 - Advanced Phase Settings

Date sheet in effect:

Date sheet voided:

Location: Hwy 97 @ Pinebrook

SHEET 3

TABLE 1 Page 0

Phase Functions (0+Key)

Function	Key	1	2	3	4	5	6	7	8
		Phase Number *							
Veh Recall	0		X				X		
Ped Recall	1								
Red Lock	2								
Yellow Lock	3								
Permit Phase	4		X		X		X		X
Ped Phases	5		X		X		X		X
Lead Phases	6	X		X		X		X	
Double Entry	7				X				X
Sequential	8								
Start Green	9		X				X		
OLA=	A								
OLB=	B								
OLC=	C								
OLD=	D								
Exclusive	E								
Sim Gap	F		X				X		

TABLE 2 Page 0

Miscellaneous (C+F+Key)

Function	Key	Value
Page ID	0	0
	1	
	2	
OL		
OL		
OL		
OL		

Keys 8 through F

Function	Key	1	2	3	4	5	6	7	8
		Phase Number							
RT OLE	8								
RT OLF	9								
Red Rest	A								
Max Recall	B								
Flash Green	C								
	D								
Advance WALK	E								
Restrictive Ph	F								

* Shown on Call/Active Display

Actuated Phasing Settings for Timing Plans and Simulation

TABLE 1 Page 0

Phase Timing (Ph. No. + Key)

Interval	Key	1	2 (Southbound Hwy 97)	3	4 (Westbound Pinebrook)	5	6 (Northbound Hwy 97)	7	8 (Eastbound ...)
		Phase Number							
Max Green	0		50		30		50		30
Max2 / HFDW	1		40		35		40		35
Walk	2		5		5		5		5
Flashing DW	3		21		21		22		25
Max Initial	4		20		5		20		5
Min Green	5		10		5		10		5
TBR	6		10		5		10		5
TTR	7		20		5		20		5
Observe Gap	8								
Passage	9		5.2		3.5		5.2		3.5
Min Gap	A		3.2		1.0		3.2		1.0
Add per Act	B		1.5				1.5		
	C		4.0		4.0		4.0		4.0
	D		1.0				1.0		
	E		5.0		5.0		5.0		5.0
	F								

Walk and Flashing Don't Walk times

To observe timing for an individual phase :
Enter C + A + F for Ring A (Phase 1-4) or
enter C + B + F for Ring B (Phase 5-8)

Page I.D. 0

Phase Conditions as shown on Free Display

00	Initial Entry	0C	Yellow
02	WALK	0D	Red Clear
03	Flashing DW	0E	Red Revert
05	Min Green	11	Gap Out
08	Rest	12	Force Off
09	Passage	14	Max Out
0B	Added Initial	15	Red Revert Timed out

TABLE 2 Page 0

		Key	Value	
Short Pwr Dn		0		Clock Correction Speed up 1 - 9 Slow down 11 - 19
Long Power Dn		1		
Preemption Delay Types	EVA	2		Preemption Delay Types: Hold 1 Latch 2 Both 3 Neither 0
	EVB	3		
	EVC	4		
	EVD	5		
	RR	6		
Ped Inhibit		7		Usually should be 0
OLA	Green	8		Overlap Yellow Time should always be specified
	Yellow	9		
OLB	Green	A		
	Yellow	B		
OLC	Green	C		
	Yellow	D		
OLD	Green	E		
	Yellow	F		

Keyboard Entries when not in Free Display

A	Advance	D	Column Advance
B	Back	E	Enter and Advance
C	Clear Display	F	Free Display

Reinitialization
D + 1 + F + 1 + E
(Use **only** when in flash)

Phase Data Copy
C + x + C + y + D
x From Phase (x cannot be 3 or 8)
y To Phase(s) - up to 3

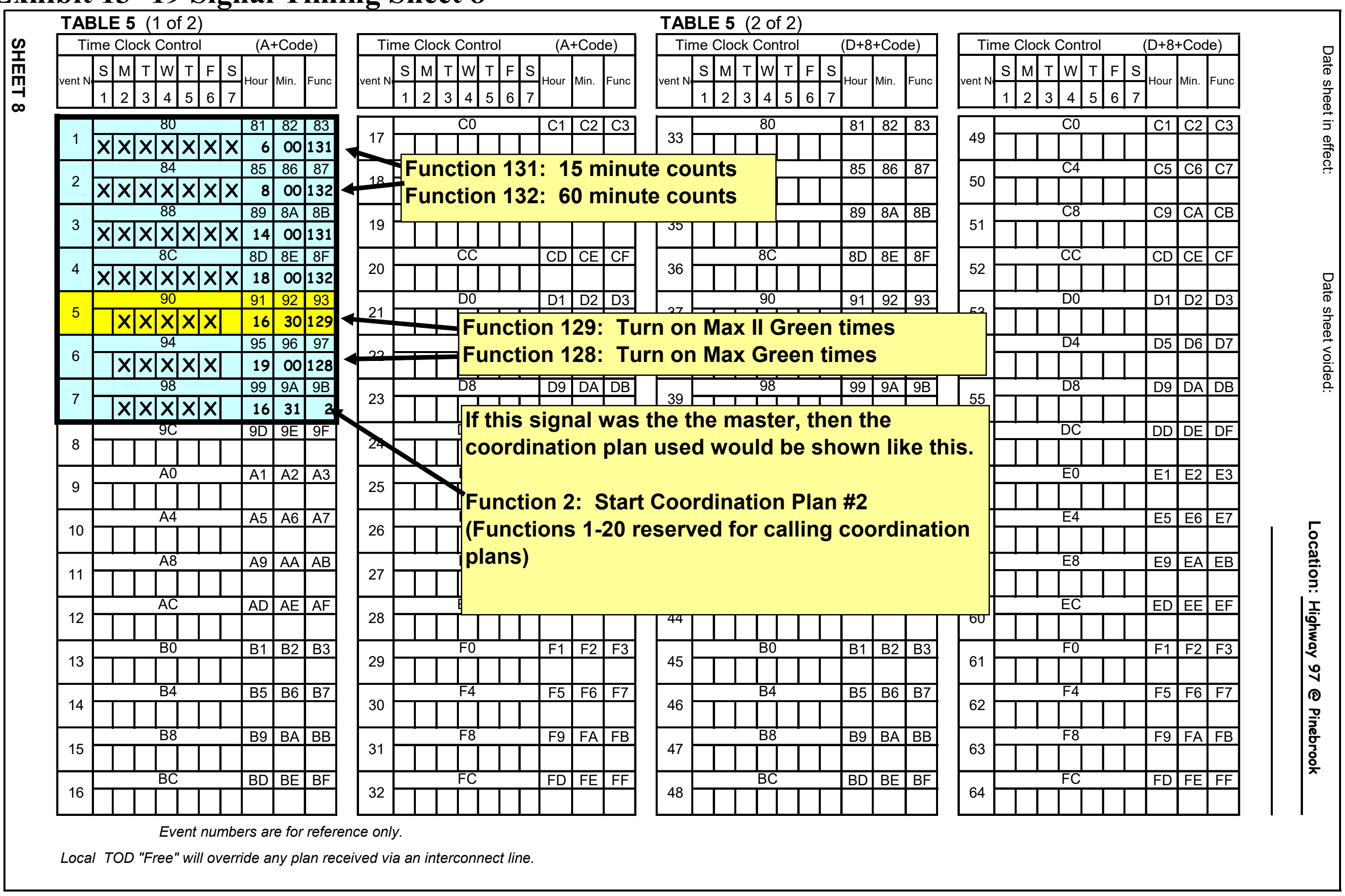
Example 13- 8 Signal Phase Splits

Example values for Sheet 3 are ():

- Vehicle Recall = Phases 2 and 6 (US 97)
- Permitted Phases = 2, 4, 6 and 8. From the phase rotation diagram in it is seen that Phase 2 and 6 on US 97 go together and Phase 4 and 8 on Pinebrook go together.
- Overlaps = No overlapping phases

If this signal was not coordinated (it isn't) then the maximum cycle length would be the maximum greens plus the yellow times plus the all-red times. In checking Sheet 8,

Exhibit 13- 19 Signal Timing Sheet 8



it is found that the max 2 green time is in effect starting at 4:30 PM, so the max 2 green time will be used to calculate the cycle length.

Maximum Cycle length = Max 2 green for Phase 2 and 6 + Max 2 green for Phase 4 and 8 + yellow x 2 phases + all-red x 1 phase = 40 + 35 + (4 x 2) + 1= 84 seconds.

Synchro phase split conversion:

1. Synchro Cycle length = 40 + 35 = 75 s
2. Maximum cycle length = 75 + 4(2) +1 = 84 s
3. Synchro Phase 2&6 = ((40 + 4 + 1) / 84) x 75 = 40 s
4. Synchro Phase 4&8 = ((35 + 4) / 84) x 75 = 35 s
5. Check = 40 +35 = 75 s = Step 1 cycle length

In the above example the differences in the phase splits are small, resulting in Synchro splits that are the same as the timing sheet splits. The splits are different if the maximum greens were used instead of the max 2 greens, as shown below.

1. Synchro Cycle length = 50 + 30 = 80 s
2. Maximum cycle length = 80 + 4(2) +1 = 89 s
3. Synchro Phase 2&6 = ((50 + 4 + 1) / 89) x 80 = 49 s
4. Synchro Phase 4&8 = ((30 + 4) / 89) x 80 = 31 s
5. Check = 49 +31 = 80 s = Step 1 cycle length

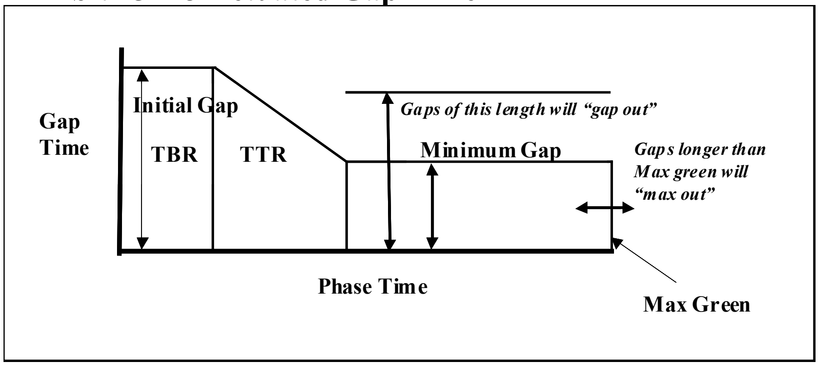
For most new actuated signals, additional settings need to be pulled from Table 1. Pedestrian settings can have a large impact on signal operation and the resulting intersection v/c especially if there are many pedestrian calls per hour on an approach. For creating a calibrated simulation, the actual pedestrian timing should be used as shown in Table 1 (Key= ph + 2 and Key = ph + 3) If the timing is not known, the ODOT standard walk time is 7.0 seconds with the curb-to-curb flashing don't walk time based on a 4.0 ft/s walk time.

Table 1 also covers the actuated signal phasing parameters that are needed for creating timing plans and calibrated simulations. These five parameters are:

- **Minimum Green** (Key= ph + 5) - Minimum green time that a signal indication will occur once the phase is served.
- **Time Before Reduce** (TBR) (Key= ph + 6) – Time elapsed before gap time is reduced
- **Time To Reduce** (TTR) (Key = ph + 7) - Time elapsed during gap time reduction to minimum.
- **Passage** (Key = ph +9) – This is the time that a phase is initially extended after a call is placed on a vehicle approach. Also known as initial gap.
- **Minimum Gap** (Key = ph + A) – Gap time after reduction until end of phase.

Exhibit 13- 16 shows the progression of the gap time from when a green indication starts at the initial gap in the TBR period down to the minimum gap time. During the TTR period, the initial gap time is reduced to the minimum gap time as specified on the timing sheet. If during the minimum gap time, the minimum gap is exceeded, then the signal will turn yellow (also known as a "gap out"). If vehicles keep approaching, the passage time will extend the green time to the maximum green time and then turn yellow (also known as a "max out"). Having a signal gap out is preferable, as dilemma vehicles (vehicles that either quickly accelerate or decelerate under yellow) can occur under max out conditions.

Exhibit 13- 15 Actuated Gap Time



<u>Sheet 6 – Table 6 Operation</u>

Table 6 indicates whether the signal is ever coordinated over the course of a day or week. If Mode (Key = B+0+4) is a non-zero value, then the intersection is coordinated. The intersection may or may not be in coordination during the analysis periods. The actual times that coordination plans are in effect are entered on Sheet 8 of the local controller or on Table 5 of the On-Street Master Controller. Exhibit 13- 16 shows that the example intersection is coordinated but is not the master.

Exhibit 13- 16 Signal Timing Sheet 6

SHEET 6

Date sheet in effect: Date sheet voided:

Location: Hwy 97 @ Pinebrook

TABLE 6 (Also see sheet 2)

Operation (B + 0 + Key)		
Key	Parameter	Value
0	Present Plan	
1	Time of Day Plan	
2	Hardwire Plan	
3	MODEM Plan	
4	Mode (0 - 4 see right)	3
5	Master (0 - 4 see right)	0
6	Master Cycle Clock	
7	Local Cycle Clock	
8	Local Timer	
9		
A		
B		

		Phase Number							
		1	2	3	4	5	6	7	8
C									
D	NEMA CNA								
E	Adv. Warn.								
F	MRI Phases		X		X		X		X

Mode:
- 0 = Free
- 1 = TBC
- 2 = Hardwire
- 3 = Modem
- 4 = TM System

Master:
- 0 = Off
- 1 = Modem Master
- 2 = Hardwire Master
- 3 = 1 + 2
- 4 = TM Master

	Y	N
OSM ?		X

OSM Location

Powers Rd.

Coordination Mode and Master Type

Function Code Index						Notes
Function		Time Clock On	Time Clock Off	Manual On	Manual Off	
Outputs	A	71	81			Phase 2 ped yellow (C1-35) (1)
	B	72	82			Phase 6 ped yellow (C1-36) (1)
	C	73	83			Phase 4 ped yellow (C1-37) (1)
	D	74	84			Phase 8 ped yellow (C1-38) (1)
TOD Red Rest		25	24			See Sheet 10 at B + C + D to set phases
TOD Max Recall		27	26			See Sheet 10 at B + A + E to set phases
TOD Ped Recall		29	28			See Sheet 10 at B + B + E to set phases
WALK 2		55	54			Use WALK 2 times set on Sheets 3, 4, 5
Plan No.		1 - 18		1 - 18	0	Sets operation to coordination plans on Sheet 7
Free		20		20		Sets operation to fully actuated
Flash		19 or 33	32	19 or 33	0	Sets operation to flash
Max 2		129	128	129	0	Use Max 2 times set on Sheets 3, 4, 5
Det. Count 15		131	130			Log Detector Counts - 15 min. intervals
Det. Count 60		132	130			Log Detector Counts - 60 min. intervals
[illegible]		[illegible]				Clear Detector Count Log
[illegible]		[illegible]	[illegible]			Enable Detector Diagnostics and log
[illegible]		[illegible]	[illegible]			Enable Detector Diagnostics without log
Clear Det Diag.		138				Clear Detector Diagnostic Log
Send Real Time		199		199		Modem master only
Time Transfer		100		100		Implements Page 0
		101		101		Implements Page 1
		102		102		Implements Page 2
Page Copy				93	---	Copies Page 0 data to Pages 1 & 2 Make sure Page 0 is the active Page
Burn EEPROM				94	---	Places active timing data into backup timing (Use reinitialization to place backup into active)
Print Out				96	0	Conect printer to C2 connector

Note

(1) These C1 pins are used for other functions. See note (5) on Sheet 2.

Manual (D + 1 + E)	

TABLE 13 (Also see Sheet 10)

Miscellaneous (E + F + Key)		
Function	Key	Time
Railroad Max 2	0	
Ped Permissive Plan 1	1	
Ped Permissive Plan 2	2	
Ped Permissive Plan 3	3	
Ped Permissive Plan 4	4	
Ped Permissive Plan 5	5	
Ped Permissive Plan 6	6	
Ped Permissive Plan 7	7	
Ped Permissive Plan 8	8	
Ped Permissive Plan 9	9	
Number of Long Powerouts	A	
Number of Short Powerouts	B	
Failed Detector Number	C	
Max 2 On	D	
No Daylight Savings	E	
Revision Level	F	

TABLE 10 (Also see Sheet 12)

(A + 3 + 9)

Sample Detectors
(0 = off, 1 = on)

Sampling detectors are assigned using extended input codes on Sheet 11

For Protected / Permissive Left Turns

(A + 3 + A)

Left Turn Type
(0, 1, or 2)

0 = Off

1 = Left turn places call on cross street

2 = Left turn is omitted until cross street is serviced

Note: This feature works only with leading left turn phases 1, 3, 5, or 7. It is used to prohibit a green arrow from immediately following a green ball.

Sheet 7 – Table 7 Coordination Timing

If a signal operates in coordinated mode, then the timing shows up in Table 7. Timing values such as lead-lag settings on Sheet 7 override the values on Sheet 3. A signal controller will not exceed the max greens from Sheet 3 nor the force-offs (when the phase is forced "off" by the clock) on Sheet 7. The cycle length shown on Sheet 7 can be directly entered into Synchro. Using the force-offs the actual phase splits can be calculated. These values can also be directly entered into Synchro.

Exhibit 13- 17 shows Table 7 for the example. In this case, Plan 2 with the 80 second cycle length is in operation during the afternoon peak. Read down the column. At 0 seconds Phases 2 and 6 are forced off. At 35 seconds Phases 4 and 8 are forced "off." Phases 2 and 6 operate from 35 seconds around to 0 seconds on the clock (80 – 35 = 45 seconds). In this case Phases 2 and 6 are 45 seconds and Phases 4 and 8 are 35 seconds. Note how this is would be different if this intersection was not coordinated, as shown under Sheet 3.

Exhibit 13- 17 Signal Timing Sheet 7

Date sheet in effect: Date sheet voided:

Location: Hwy 97 @ Pinebrook

TABLE 7 (1 of 2)

Hardwire Conversion	Dial Offset	1			2			3			
		1	2	3	1	2	3	1	2	3	
Parameter	**Key**	**Coordination Timing (B + Plan No. + Key)**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Plan Number
Cycle Length	0	70	80								
Forceoffs for Phase Indicated by Key No.	1										
	2	0	0								
	3										
	4	31	35								
	5										
	6	0	0								
	7										
	8	31	35								
Offset	9	45	48								
Permissive	A	2	2								
Max. Dwell	B	30	35								

Coordination Timing Plans

Plan #2 is used in the example.

Sheet 8 of the master controller shows when each plan is in effect.

Plan			1	2	3	4	5	6	7	8
1	C	Lead Phases	X		X		X		X	
	D	Coord. Phases		X				X		
	E	Perm. 2 Ph.								
	F	Min. Recall								
2	C	Lead Phases	X		X		X		X	
	D	Coord. Phases		X				X		
	E	Perm. 2 Ph.								
	F	Min. Recall								
3	C	Lead Phases								
	D	Coord. Phases								
	E	Perm. 2 Ph.								
	F	Min. Recall								
4	C	Lead Phases								
	D	Coord. Phases								
	E	Perm. 2 Ph.								
	F	Min. Recall								
5	C	Lead Phases								
	D	Coord. Phases								
	E	Perm. 2 Ph.								
	F	Min. Recall								
6	C	Lead Phases								
	D	Coord. Phases								
	E	Perm. 2 Ph.								
	F	Min. Recall								
8	C	Lead Phases								
	D	Coord. Phases								
	E	Perm. 2 Ph.								
	F	Min. Recall								
9	C	Lead Phases								
	D	Coord. Phases								
	E	Perm. 2 Ph.								
	F	Min. Recall								

TABLE 7 (2 of 2)

Parameter	**Key 2**	**Coordination Timing (B + D + Key 1 + Key 2)**									
		10	11	12	13	14	15	16	17	18	Plan Number
		7	**8**	**9**	**A**	**B**	**C**	**D**	**E**	**F**	**Key 1**
Cycle Length	0										
Forceoffs for Phase Indicated by Key No.	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
Offset	9										
Permissive	A										
Max. Dwell	B										

Plan			1	2	3	4	5	6	7	8
10	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
11	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
12	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
13	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
14	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
15	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
16	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
17	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								
18	C	Lead Phases								
	D	Coord. Phases								
	E									
	F	Min. Recall								

SHEET 7

Sheet 8 – Table 5 Time Clock Control

Table 5 shows the times that various timing plans and max greens are in effect for a particular intersection. In the absence of timing sheets from an on-street master controller (noted as "OSM" on the front of the timing sheet), the analyst will have to contact Region Traffic to verify which timing plan on Sheet 7 is in effect during the desired analysis period. Generally, during the PM peak plan #2 is in effect. The master controller would indicate in Table 5 which coordination plan shown on Sheet 7 would be operating at any given time. The function codes in the right-hand column in Table 5 can tell the analyst what maximum green applies. Code 128 is for the maximum green while Code 129 is for the max 2 green. Codes 100, 101 and 102 apply to Page 0, 1, 2 (on Sheets 3, 4 or 5) respectively, so the analyst can determine what phase timing is in effect. Codes 131 and 132 are just to tell the controller to count the traffic volume data in 15-minute intervals or 60-minute intervals, respectively.

Exhibit 13- 19 shows the timing plans in effect for the example intersection. The controller for this intersection is coordinated but is not the master. If this signal was not coordinated, Code 129 would be indicated starting at 4:30 PM, in which case the max 2 green would be used for calculating the cycle length and phase splits.

If this controller was the master controller, an event would be listed showing when each plan went into effect. Event 7 has been added to the table to illustrate this.

Exhibit 13- 18 Signal Timing Sheet 8

SHEET 8

TABLE 5 (1 of 2)

Time Clock Control (A+Code)

Event No	S 1	M 2	T 3	W 4	T 5	F 6	S 7	Hour	Min.	Func
1	80							81	82	83
	X	X	X	X	X	X	X	6	00	131
2	84							85	86	87
	X	X	X	X	X	X	X	8	00	132
3	88							89	8A	8B
	X	X	X	X	X	X	X	14	00	131
4	8C							8D	8E	8F
	X	X	X	X	X	X	X	18	00	132
5	90							91	92	93
		X	X	X	X	X		16	30	129
6	94							95	96	97
		X	X	X	X	X		19	00	128
7	98							99	9A	9B
		X	X	X	X	X		16	31	2
8	9C							9D	9E	9F
9	A0							A1	A2	A3
10	A4							A5	A6	A7
11	A8							A9	AA	AB
12	AC							AD	AE	AF
13	B0							B1	B2	B3
14	B4							B5	B6	B7
15	B8							B9	BA	BB
16	BC							BD	BE	BF

Time Clock Control (A+Code)

Event No	S 1	M 2	T 3	W 4	T 5	F 6	S 7	Hour	Min.	Func
17	C0							C1	C2	C3
18										
19										
20	CC							CD	CE	CF
21	D0							D1	D2	D3
22										
23	D8							D9	DA	DB
24										
25										
26										
27										
28										
29	F0							F1	F2	F3
30	F4							F5	F6	F7
31	F8							F9	FA	FB
32	FC							FD	FE	FF

TABLE 5 (2 of 2)

Time Clock Control (D+8+Code)

Event No	S 1	M 2	T 3	W 4	T 5	F 6	S 7	Hour	Min.	Func
33	80							81	82	83
								85	86	87
35								89	8A	8B
36	8C							8D	8E	8F
37	90							91	92	93
39	98							99	9A	9B
44										
45	B0							B1	B2	B3
46	B4							B5	B6	B7
47	B8							B9	BA	BB
48	BC							BD	BE	BF

Time Clock Control (D+8+Code)

Event No	S 1	M 2	T 3	W 4	T 5	F 6	S 7	Hour	Min.	Func
49	C0							C1	C2	C3
50	C4							C5	C6	C7
51	C8							C9	CA	CB
52	CC							CD	CE	CF
53	D0							D1	D2	D3
	D4							D5	D6	D7
55	D8							D9	DA	DB
	DC							DD	DE	DF
	E0							E1	E2	E3
	E4							E5	E6	E7
	E8							E9	EA	EB
60	EC							ED	EE	EF
61	F0							F1	F2	F3
62	F4							F5	F6	F7
63	F8							F9	FA	FB
64	FC							FD	FE	FF

Function 131: 15 minute counts
Function 132: 60 minute counts

Function 129: Turn on Max II Green times
Function 128: Turn on Max Green times

If this signal was the the master, then the coordination plan used would be shown like this.

Function 2: Start Coordination Plan #2
(Functions 1-20 reserved for calling coordination plans)

Date sheet in effect:

Date sheet voided:

Location: Highway 97 @ Pinebrook

Event numbers are for reference only.

Local TOD "Free" will override any plan received via an interconnect line.

13.4.6 Progression Analysis

This section pertains to planning analyses as provided for traffic signal engineering investigations, corridor studies and other planning efforts. Oregon Administrative Rule (OAR) 734-020-0480 stipulates that a progression analysis is required for the approval of new or revised traffic signal systems if the proposed location is within ½ mile of an existing or possible future traffic signal. The roadway segment analyzed, to the extent possible, shall include all traffic signals in the existing or future traffic signal system. The purpose of a planning progression analysis is to ensure that a new signal or revised traffic signal will function acceptably with other nearby signals.

At the start of a project, ODOT traffic operations staff will determine whether the analyst should use the existing signal timings for all analysis scenarios or develop optimized timings for the coordinated system. If the existing timings are to be used in the analysis, Region traffic shall provide timing files, timing sheets or Synchro files of the existing settings. If optimized timings are to be developed, those settings are subject to approval by ODOT and those conditions become the baseline for all comparisons. The following settings should be optimized for each analysis scenario when the analyst is asked to use optimum coordination settings:

- Cycle Length;
- Side Street Phase Lengths (Splits);
- Phase Sequence (Lead/Lag Left Turns);
- Intersection Offsets; and
- Link Speed or Progression Speed

The optimum settings must meet the criteria established in OAR 734-020-0480 as it relates to progression analysis while also attempting to find the lowest intersection v/c ratio and minimizing queue lengths. This OAR only applies when modifications are proposed to a signal which would affect the settings of the coordination plans. Examples of these modifications are changes in cycle length, decreased green time for mainline, additional phases, longer crosswalks and intersection relocation.

Requirements for Signal Progression Analysis

For planning analysis, the following requirements must be met:

- Demonstrate acceptable existing and future traffic signal system operation during commute peak hours
- Provide for a progressed traffic band speed within 5 mph of the existing posted speed for both directions of travel during the off-peak periods and within 10 mph of the existing posted speed during peak periods. Approval by the State Traffic Engineer or designated representative shall be required where speeds deviate more than the above.
- Demonstrate sufficient vehicle storage is available at all locations within the traffic signal system without encroaching on the functional boundaries of adjacent

lanes and signalized intersections. The functional boundary of an intersection shall be determined using procedures specified by the ODOT Access Management Unit.

- Provide a common cycle length with adequate pedestrian crossing times at all signalized intersections.

The analysis must demonstrate that the additional or revised signal still allows the signal system to have a progression bandwidth as large as that required or as presently exists, for through traffic on the state highway at the most critical intersection within the roadway segment. The most critical intersection is the intersection carrying the highest through volume per lane on the state highway. Unless directed otherwise by ODOT traffic signal operations staff, the analysis should use optimized timing settings. The carrying capacity of the progression bandwidth should be estimated with the following equation:

$$\text{Bandwidth Capacity (veh/cycle)} = \frac{(\text{Bandwidth(sec)} - 4) \times (\text{Adj. Sat. Flow Rate})}{3600}$$

This capacity should be compared with the average platoon size expected to arrive at the most critical intersection for both directions of travel. The average platoon size may be found by the following simplified calculation.

$$\text{Average Platoon Size} = \frac{C * V}{3600}$$

where:

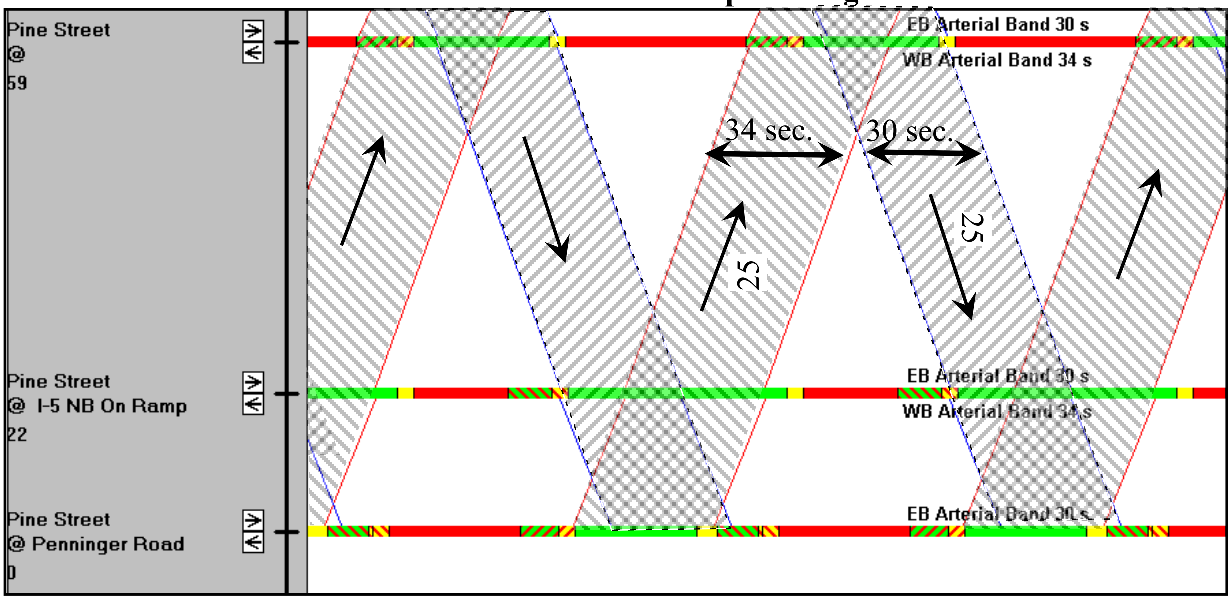
C = cycle length
V = volume (adjusted for PHF)

Complete time-space diagrams are required for each of the analysis scenarios, including the existing coordinated system. They should indicate the offsets, phasing and split times for each of the signals in the system. If using Synchro, the bandwidth shall be reported for the maximum green times or the 90th percentile arrival rates. The reported bandwidth may include green and yellow clearance times. An example time-space diagram is shown in Exhibit 13- 19.

If the analysis shows that the proposed signal will not meet the requirements of OAR 734-020-480, other alternatives should be evaluated. These may include:

- Moving the new/revised intersection;
- Reducing phases on one or more signals;
- Providing additional lanes to reduce side street green or increase mainline capacity
- Decrease side street demands through TDM measures or construction of alternative routes.

Exhibit 13- 19 Illustration of Bandwidths on a Time-Space Diagram



To implement the requirements of OAR 734-020-480, analysts may use the coordinated system software program of their choice (see Section 13.5). Hand calculations and time-space diagrams are also acceptable. Refer to Appendix 13A for settings for each of these tools.

Microsimulation programs such as SimTraffic, CORSIM and Vissim do not produce signal progression timing. They can model signal progression timing as an input. SimTraffic automatically models progression timing developed in Synchro. Refer to Chapter 15 for simulation guidance.

13.5 Estimating Queue Lengths for Signalized Intersections

For signalized movements, queue length estimates are most often recommended to be calculated using traffic analysis software. The use of software in estimating vehicle queue lengths can often be conducted simultaneously with capacity analysis, which can make it a very convenient method. There are many different software programs available that provide queue length estimates. However, caution should be used in selecting one as results may vary significantly between programs. As an example, the HCS has been found to produce consistently poor queue length estimates as compared to field measurements and should not be used for this purpose.

The minimum storage length for urban or rural left turn lanes at signalized intersections on state highways is 100 feet. Left Turn Lane layouts/dimensions are available in HDM Section 500 and Traffic Line Manual (TLM) Section 310.

Whether queue lengths have been calculated through manual methods or computer software, as a general rule-of-thumb the installation of signalized turn lanes with more than 350-feet of storage should be reconsidered through discussions with Region Traffic. In some cases, it may be preferable to install dual turn lanes with shorter storage bays.

For the estimation of queues at intersections belonging to a coordinated signal system, over-capacity conditions and areas where queue spill-back may be a problem, it is recommended that simulation software be used to report the 95th percentile queues. Refer to Chapter 15 for further information.

However, manual methods are also available that can offer acceptable estimates without requiring access to a computer. In either case, engineering judgment should be used to discern whether the results obtained are reasonable.

13.5.1 Manual Methods

Manual methods offer a practical means of estimating queue lengths with little equipment or data required. While they can produce reasonable results, unless otherwise noted, they are generally recommended for planning-level analysis, with the use of specialized software preferred for design purposes.

13.5.2 Left Turn Movement Queue Estimation Technique

A “rule of thumb” equation[3] that can be used to manually estimate queue lengths for single lane left turn movements is shown below.

Storage Length = (Volume/Number of Cycles Per Hour) x (t) x (25-feet)

Where “t” is a variable, the value of which is selected based on the minimum acceptable likelihood that the storage length will be adequate to store the longest expected queue. Suggested values are listed in Exhibit 13- 20. Typically, transportation analysis uses the 95th percentile queue.

Exhibit 13- 20 Selection of "t" Values

Minimum "t" Value	Percentile
2.0	98 %
1.85	95 %
1.75	90 %
1.0	50 %

[3] *Discussion Paper No. 10: Left-Turn Bays*, Transportation Research Institute, Oregon State University, 1996, p. 17.

It should also be noted that the value of 25-feet used in the equation represents the average storage length required for a passenger car. If a significant number of trucks are present in the turning volumes, the average storage length per vehicle should be increased, as shown in Exhibit 13- 21. This adjustment is only for manual methods; software packages may require a different adjustment.

Exhibit 13- 21 Storage Length Adjustments for Trucks

Percent Trucks in Turning Volume	Average Vehicle Storage Length
< 2%	25 ft
5%	27 ft
10%	29 ft

While the rule of thumb equation is intended for use in estimating vehicle queue lengths for single lane left turn movements, the vehicle queue lengths for double left turn lanes can be estimated by dividing the results of this method by 1.8. This value represents the assumption that queued vehicles will not be evenly distributed between the turn lanes.

13.5.3 Right Turn Movement Queue Estimation Techniques

A similar rule of thumb equation, sometimes referred to as the "red time" formula[4], is also available for signalized single lane right turn queue estimates. It is represented by the following equation.

Storage Length = (1-G/C) (V) (K) (25-feet) / (Number of Cycles Per Hour) (N_L)

where:

G = Green time provided for the right turn movement
C = cycle length
V = right turning volume
K = random arrival factor
N_L = number of right turn lanes

A value of 2 should be used for the random arrival factor (K) where right-turn-on-red is prohibited. Where right-turn-on-red is allowed, a value of 1.5 should be used.

As with the equation for left turn queue estimates, the value of 25-feet used in the equation represents the average storage length required for a passenger car. If a significant number of trucks are present in the turning volumes, the average storage length per vehicle should be increased in the same manner recommended for the left turn queue estimate using .

[4]Koepke, F. J., Levinson, H. S., *Access Management Guidelines for Activity Centers*, NCHRP Report 348, TRB, Washington, D.C., 1992, p. 99.

Another, less accurate, method for manually estimating vehicle queue lengths is using the assumption that “V” vehicles per hour per lane entering a signalized lane with a cycle length of 90 seconds will produce a “V”-foot-long queue per lane. For example, if the volume turning left from a dual left turn lane is 400 vehicles per hour, a ballpark queue length estimate would be 400/2 = 200 feet per lane.

13.6 Available Analysis Tools

A few of the computer software programs capable of performing operational, progression, and queuing analysis of signalized intersections include:

Synchro is a software application for optimizing traffic signal timing and performing capacity analysis. The software optimizes splits, offsets and cycle lengths for individual intersections, an arterial or a complete network. Synchro performs capacity analysis using current HCM methods. Synchro provides detailed time space diagrams that can show vehicle paths or bandwidths. Synchro can be used for creating data files for SimTraffic and other third-party traffic software packages. The software supports the Universal Traffic Data Format (UTDF) for exchanging data with signal controller systems and other software packages. Synchro is used in conjunction with SimTraffic for microsimulation analysis (refer to Chapter 15).

Vistro is a software application for optimizing traffic signal timing and performing capacity analysis. The software optimizes splits, offsets, and cycle lengths for individual intersections, an arterial or a complete network. Vistro performs capacity analysis using current HCM methods. Has embedded graphics to create customized reports including volume figures. Can create HCM 7th edition critical intersection v/c ratios without extra calculations or use of HCM 2000. Works well for multiple scenarios for a single intersection in the same file, such as all-way stop, two-way stop, roundabout, and signalized intersection. Can be used as a starting point to create a Vissim simulation network, or to detail a network from Visum. Refer to Appendix 8B PTV network setup guide. Good for lot of scenario management. Vistro is used in conjunction with Vissim for microsimulation analysis (refer to Chapter 15).

SIDRA is a software application for optimizing traffic signal timing and performing capacity analysis. The software optimizes splits, offsets, and cycle lengths for individual intersections, an arterial or a complete network. SIDRA performs capacity analysis using current HCM methods and offers enhancements through extensions. SIDRA will also reduce lane capacities in a network based on oversaturated upstream or downstream segments. Full flexibility to handle non-standard intersections easily (e.g. three-way stops), multiple modes (e.g. bicycles, streetcars) and related facilities (e.g. bus lane).

[Appendix 12A/13A – Software and Settings for Intersection Analysis]

References

1 Nevers, B., H. Steyn, Y. Mereszczak, Z. Clark, N. Rouphail, J. Hummer, B. Schroeder, Z. Bugg, J. Bonneson, and D. Rhodes. *NCHRP Report 707: Guidelines on the Use of Auxiliary Through Lanes at Signalized Intersections.* Transportation Research Board of the National Academies, Washington, D.C., 2011.

2 Thomas Creasey, F & Stamatiadis, Nick & Viele, Kert. (2011). Right-Turn-on-Red Volume Estimation and Incremental Capacity Models for Shared Lanes at Signalized Intersections. Transportation Research Record: Journal of the Transportation Research Board. 2257. 31-39. 10.3141/2257-04.

3 Right-Turn-on-Red Volume Estimation and Incremental Capacity Models for Shared Lanes at Signalized Intersections, F. Creasey, Nikiforos Stamatiadis, Kert Viele, Transportation Research Record: Journal of the Transportation Research Board Dec 2011, Vol. 2257, pp. 31-39

4 *Right Turn on Red Study Minnesota*, Finkelstein, Jonah et al, Spack Consulting, 2017