MnDOT Traffic Signal Timing and Coordination Manual

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1 OVERVIEW

1.1 Introduction

No other device has such a daily impact on virtually every citizen as does the common, ever-present traffic signal. The trip to work is punctuated by stops at traffic signals, even on uncongested routes. Drivers place their physical safety and that of their passengers confidently in the signal's ability to give them the right-of-way.

A signal's necessity is accepted by the citizen, and in fact demanded in some cases, to assure safety and mobility. The same citizen quietly assumes that the operating agency knows how to best operate the signals, and reluctantly reports only the most obvious failures. Inefficient signal operation, even though such operation is silently stealing dollars from the user's pocket in increased fuel costs, longer trip time, etc. is rarely reported or noticed by the user. In the user's view, the signals are working and if they are sub-optimal, it becomes a concern but not a crisis.

The overall objective of signal control is to provide for the safe and efficient traffic flow at intersections, along routes and in street networks. A well timed signal system can reduce fuel consumption, eliminate unnecessary stops and delays, improve safety and enhance the environment.

1.2 Timing Goals

When signals are installed in accordance with the warrants listed in the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD), they can provide specific advantages in traffic control and safety. They can, however, also have certain negative impacts that may or may not apply at a particular location.

Some of the advantages (goals) of signal installations include:

- ✓ Provide for the orderly movement of traffic;
- ✓ Reduce the frequency of certain types of crashes (i.e., right-angle and pedestrian);
- ✓ Increase the traffic handling capacity of the intersection;
- ✓ Provide a means of interrupting heavy traffic to allow other traffic, both vehicular and pedestrian, to enter or cross;
- ✓ Provide for nearly continuous movement of traffic at a desired speed along a given route by coordination;
- ✓ Afford considerable economy over manual control at intersections where alternate assignment of right-of-way is required; and,
- ✓ Promote driver confidence by assigning right-of-way.

Some disadvantages to signal installations include:

- ✓ Most installations increase total intersection delay and fuel consumption, especially during off peak periods.
- ✓ Probably increase certain types of crashes (i.e., rear end collisions).
- ✓ When improperly located, cause unnecessary delay and promote disrespect for this type of control.
- ✓ When improperly timed cause excessive delay, increasing driver irritation.

Review of Signal Timing

The operation of the traffic signal should be observed at least once a year. A complete signal timing analysis and operation check of the traffic signal should be made every three to five years.

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2 DATA COLLECTION AND INFORMATION NEEDED

2.1 Data Collection

Data collection is a vital element of the traffic signal timing process, therefore it is important to develop a data collection plan. The plan should outline the data to be collected, the parties responsible for collecting the data, and the schedule for collecting the data.

The data should include, but is not limited to:

- ✓ Intersection geometry, including lane usage and link distances.
- ✓ Existing Intersection Turning Movement Counts
- ✓ AM peak hour (minimum 2 hours - 15 minute periods)
- ✓ PM peak hour (minimum 2 hours - 15 minute periods)
- ✓ Off peak period or any other special traffic period
- ✓ Count vehicles and pedestrians (Seasonal counts if required)
- ✓ 24 hour approach counts (preferably over a 7 day period)
- ✓ Posted speed on each approach
- ✓ Crash reports or preferably collision diagrams representing past 3 years for urban locations (consider 5 years in rural locations)
- ✓ Percent of heavy vehicles
- ✓ Field Studies, including travel time runs and approach delay studies. This data will be used in the calibration of the computer models and for comparison to similar data collected in the "after" condition.
- ✓ Signal Timing and Phasing Data
- ✓ Existing Traffic Signal Hardware. This information should include controller equipment, communications details, vehicle detectors and traffic signal heads. This information can be used to determine the phasing/timing capabilities at each intersection. For example, could a protected left-turn phase be added?
- ✓ Additional Data. These may include items such as pedestrian counts, traffic counts of mid-block generators, early-release studies, etc.

All data should be current and representative of the intersection. Turning movement counts used should be within one year of implementing the timing plan or recent enough to reflect current conditions.

2.2 Geometric Conditions

Intersection geometry is generally presented in diagrammatic form and must include all of the relevant information, including approach grades, the number and width of lanes, and parking conditions. The existence of exclusive left- or right-turn lanes should be noted, along with the storage lengths of such lanes.

When the specifics of geometry are to be designed, these features must be assumed for the analysis to continue. State or local policies and guidelines should be used in establishing the trial design.

In order to recreate your study area's streets and intersections in Synchro (see Chapter 6), it helps to map out the signalized intersections, the connecting links and the external links on paper first. One option is to make a photocopy of a detailed map of the study area so that you can draw on it. Another option, if you have a street map of your study area in a format accepted by Synchro (jpg, bmp, dxf, sid or shp), is to import it into Synchro to help with the map layout. If you are using accurate basemaps, the distances and angles can be traced on the basemap. See Chapter 6 of this book for details on importing a Synchro basemap.

2.3 Volume Studies

Purpose

Traffic volume studies are conducted to obtain factual data concerning the movement of vehicles and/or persons at selected points on the street or highway system. Volume data are expressed in relation to time, the base being determined by the type of information desired and the application in which it is to be used. Some typical volume studies include:

- ✓ Annual Traffic in vehicles per year.
- ✓ Average Daily Traffic (ADT) or Average Annual Daily Traffic (AADT) in vehicles per day.
- ✓ Hourly Traffic in vehicles per hour.
- ✓ *Short Term Counts* (covering 5, 6, 10, or 15 min. intervals) usually expanded into hourly flow rates.
- ✓ *Density of Traffic* in vehicles per mile.

Types

The volume studies applicable to signal timing projects include:

- ✓ *Directional Counts,* are used for determining signal timing and justifying traffic controls.
- ✓ *Turning Movement Counts*, which count all movements at the intersection, are used in computing capacity and evaluating congestion.
- ✓ *Classification Counts* are used to determine the various types of vehicle classes in the traffic stream (i.e., to determine the percent trucks for capacity analysis).
- ✓ *Pedestrian Counts* are used to justify signals, time traffic signals and compute the capacity and LOS.

Counting Techniques

Following are some of the methods used to obtain the counts described above.

Machine Counts are used to obtain vehicular counts at non-intersection locations. Total volumes, directional volumes, or lane volumes can be obtained, depending on the equipment available.

- ✓ *Permanent Counters* are installed to obtain control counts on a continuous basis. Such counts are used to provide factors for adjusting short counts to ADT and for finding the 30th highest or other hour of the year. Loop detectors are the most commonly used, especially on high volume multilane roads, because they can distinguish vehicles in individual lanes and are generally low maintenance.
- ✓ Portable Counters provide a permanent record of volumes by printing totals on a paper tape, by drawing a trace on a graph, by punching a paper tape, or by storing the data in memory (i.e., ITC ACE, Numetrics, etc.) for later direct transfer to a printer or microcomputer. A common means of gathering the data is through the use of rubber road tubes. New technology is providing expanded capabilities in this area.
- ✓ Video Counting units essentially conduct turning movement counts using off-line video collection and detection algorithms to "count" the movement volumes for the designated periods. Hybrid video counting equipment is also available where the counts are manually collected with a count board connected to your PC, however, done so in the office via looking at video recorded at the intersection.

Volume data traditionally has been gathered over periods to bracket the peak hours (3 to 4 hour periods). With video data colelction, it is now common to gather data over an extended period of time (24 hours or more).

Manual Counts must be used in those studies where desired data cannot be obtained by machine counters. For light volumes, tally marks on a form are adequate. Manually operated tally counters are available for heavier volumes. Electronic intersection assemblies with memories which record and store the totals

accumulated on each of 16 manually operated counters at a 1 to 15 minute intervals for later input into computers are available (such as the JAMAR count boards). New technology is providing expanded capabilities in this area as well. Manual counts are used for:

- ✓ Turning and through movement studies.
- ✓ Classification studies (however, some detectors and machine counters can classify vehicles by their length).
- ✓ Pedestrian studies.
- ✓ Other studies when the number of machine counters is insufficient.

Counting Periods

The time and length that a specific location should be counted also depends on the data desired and the application in which the data are to be used. Data collected for signal timing projects often get used for other applications.

Some of the more commonly used intervals are:

- ✓ 24-hour counts normally covering any 24-hour period between noon Monday and noon Friday. (Traffic on Monday mornings and Friday afternoons often varies from the normal patterns.) If a specific day count is desired, the count should be taken from midnight to midnight.
- ✓ 16-hour counts usually covering 5:30 am - 9:30 p.m. or 6 am to 10 p.m. This period contains most of the daily flow including evening traffic.
- ✓ 12-hour counts usually covering 7 am to 7 p.m. However, these may not capture all of the major traffic flows.
- ✓ Peak period counting times vary depending upon size of metropolitan area, proximity to major generators (such as the CBD or industrial areas), and the type of facility (freeway, radial arterial, etc.). Commonly used periods are 6 am - 9 am and 3 pm - 6 pm.
- ✓ Weekend counts covering the period from noon on Friday to noon on Monday. Used to develop special weekend timing plans.

Special conditions counts such as:

- ✓ Special events (holidays, sporting events, etc.).
- ✓ Abnormal weather conditions.
- ✓ Temporary closure of streets affecting the volume patterns.

Adjustment factors can be applied to the data to remove seasonal or other variations, to provide a realistic estimate of the average volume condition, and/or to expand a count to a volume estimate of a longer count period.

Turning Movement Counts

To fully analyze an intersection or system, turning movement counts at each intersection must be known, including left turns, through, right and U-turns. These data should always be obtained from field studies for operational or signal timing design studies. An example of typical turning movement data is shown in the Table on the following page.

The data was taken over two hours during the am peak and includes the 15 minute turning movement volumes, the hour total volumes, the peak hour volume for each movement, the peak hour volume for the intersection, and the peak hour factor.

The traffic software programs (Synchro, PASSER, TRANSYT) require that the data be converted into <u>hourly</u> turning movement counts. The example that follows illustrates two ways to present the data in peak hour volumes. The following defines how each are calculated and used.

Actual counting periods will vary by project and are typically within 1.5 to 2 hours plus and minus from the period (a.m., p.m., noon) peak hours. The use of video data collection techniques have greatly expanded the ability to gather turning movement counts over longer periods of the day. These longer periods are useful for determining signal timing plans and phasing operation throughout the day. For example, the use of a permissive Flashing Yellow Arrow (FYA) indication may be changed on a time of day basis based on the traffic volumes.

Exhibit 2-1 Sample Turning Movement Count

TURNING MOVMENT VOLUME DATA

Start Time	Southbound				Westbound				Northbound				Eastbound				
	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	
Movement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
7:00	0	17	8	34	0	16	65	5	0	4	4	2	0	8	103	5	271
7:15	0	14	12	23	0	20	76	10	0	9	9	5	0	10	111	8	307
7:30	0	14	8	52	0	17	70	7	0	11	5	5	0	9	151	9	358
7:45	0	14	9	34	0	16	94	18	0	10	3	10	0	11	130	12	361
Hr. Tot.	0	59	37	143	0	69	305	40	0	34	21	22	0	38	495	34	1297
8:00	0	17	5	26	0	19	92	9	0	11	12	8	0	11	99	7	316
8:15	0	22	7	30	0	23	96	10	0	9	3	8	0	9	93	9	319
8:30	0	15	7	36	0	17	96	9	0	8	5	6	0	13	113	11	336
8:45	0	23	13	29	0	13	94	22	0	9	4	12	0	4	102	9	334
Hour Total	0	77	32	121	0	72	378	50	0	37	24	34	0	37	407	36	1305

Peak Hour Analysis

	Southbound				Westbound				Northbound				Eastbound				
	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Total
1. Peak Hour of Intersection	0	67	29	142	0	75	352	44	0	41	23	31	0	40	473	37	1354
St. Time	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30
2. Peak 15 min x 4	0	88	36	208	0	92	384	72	0	44	48	40	0	44	604	48	1708

Peak Hour Factor

Method 1.		0.76	0.81	0.68		0.82	0.92	0.61		0.93	0.48	0.78		0.91	0.78	0.77	0.79
Method 2.		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00	1.00

Peak Hour of Intersection - Method 1

- ✓ Determine the highest total intersection hourly volume. This can be any four consecutive 15-minute periods in the count duration. For the example, it is as follows:

Total
271
307
358
361
316
319
336
334

Highest four consecutive 15 minute counts = 1,354 vph.

- ✓ Calculate the hourly volume for each movement. Use the same four consecutive 15 minute periods as used in step a) above. For example, the peak hour volume for the westbound through movement is calculated as follows (start at 7:30):
  70 + 94 + 92 + 96 = 352 vph.
- ✓ Calculate the movement and intersection Peak Hour Factors (PHF). The Peak Hour Factor is used to determine the traffic flow rate during the busiest 15-minute period. To determine the PHF, divide the peak hour volume computed in step b) by the highest 15 minute count in the peak interval multiplied by four. For example, the PHF for the westbound through movement is:
  Hourly Flow Rate = 352 vph

  Peak 15 minute count = 96 vph

  PHF = 352 / (96 x 4) = 0.92

Peak 15 Minutes times Four - Method 2

- ✓ Determine the highest total intersection hourly volume as described in step 1a) above.
- ✓ Calculate each movement hourly volume by determining the highest 15 minute count in the peak interval and multiplying by four. For example, the hourly volume for the westbound through movement is:
  96 x 4 = 384 vph.
- ✓ Since this method explicitly accounts for the traffic during the busiest 15 minute period, the PHF is set equal to 1.0

Identifying the 15-minute period having the highest volume may require more than just counting volumes in each of four 15-minute periods in an hour. The ideal data collection system should include cycle-by-cycle counts of discharge volumes for each lane group, so that the peak 15-minute period can be selected more accurately than with 15-minute counts.

When the traffic flow in a lane group is saturated, the cycle-by-cycle counts of discharge volumes should be supplemented by counts of the overflow queue at the end of the yellow for each cycle. Arrival volumes can then be computed from the cycle-by-cycle counts of discharge volumes and the number of vehicles in each overflow queue.

The following link URL is a link to the MnDOT Metro Intersection Warrant Information Website where traffic data can be obtained.

http://www.dot.state.mn.us/metro/warrant/

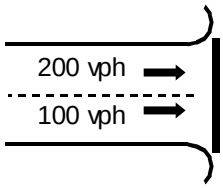
Lane Utilization Factor

When there is more than one lane in a lane group, the traffic will not use all the lanes equally. The Lane Utilization Factor affects the Saturated Flow Rate.

Exhibit 2-2 Lane Group Default Lane Utilization Factors

Lane Group Movements	# of Lanes	Lane Utilization Factor
Thru or shared	1	1.00
Thru or shared	2	0.95
Thru or shared	3	0.91
Thru or shared	4+	0.86
Left	1	1.00
Left	2	0.97
Left	3+	0.94
Right	1	1.00
Right	2	0.88
Right	3	0.76

The lane utilization factor can be calculated as follows:



$$fLU = \frac{\text{Total App. Vol.}}{\text{(No. of Lanes) x (High Lane Vol.)}} = \frac{(100 + 200)}{(2 \times 200)} = 0.75$$

See Synchro section for further details.

2.4 Travel Time & Delay Studies

Definitions

- ✓ Travel Time Study. A study conducted to determine the amount of time required to traverse a specific route or section of a street or highway. The data obtained provide travel time and travel speed information but not necessarily delay. This term is often used to include speed and delay studies.
- ✓ Delay Study. A study made to provide information concerning the amount, cause, location, duration, and frequency of delays as well as travel time and similar values.
- ✓ Travel Time. The total elapsed time of travel, including stops and delay, necessary for a vehicle to travel from one point to another over a specified route under existing traffic conditions.
- ✓ Running Time. That portion of the travel time that the vehicle is actually in motion. Running time is equal to travel time minus stopped-time delay.
- ✓ Travel Speed. The over-all average speed along a specified route of a street or highway. Travel speed is computed by dividing the total distance by the travel time.
- ✓ Running Speed. The average speed along the specified route when the stopped time is removed from the computations. Running speed is distance divided by running time.

- ✓ Delay. The time lost by traffic due to traffic friction and traffic control devices.
- ✓ Fixed Delay. The delay to which a vehicle is subjected regardless of the amount of traffic volume and interference present.
- ✓ Operational Delay. The delay caused by interference from other components of the traffic stream. Examples include time lost while waiting for a gap in a conflicting traffic stream, or resulting from congestion, parking maneuvers, pedestrians, and turning movements.
- ✓ Stopped Delay. The time a vehicle is not moving.
- ✓ Travel Time Delay. The difference between the actual time required to traverse a section of street or highway and the time corresponding to the average speed of traffic under uncongested conditions. It includes acceleration and deceleration delay in addition to stopped delay.
- ✓ Approach Delay. Travel time delay encountered at the approach to an intersection.
- ✓ Total Vehicle Delay. The total time lost, in vehicle-minutes per mile, by vehicles in a traffic stream because the street or section does not meet the suggested minimum standards. It is obtained by multiplying the peak-hour one-direction volumes by the delay rate.

Need for Travel Time or Delay Data

Congestion can be evaluated by means of speed and delay studies. Data are obtained on the amount, location, and cause of delay; the delay data also indicates locations where other studies are needed to determine the proper remedy.

Traffic signal timing studies often require travel time data at periodic intervals.

Before-and-after studies may utilize these data to determine the effectiveness of a change in signal timings, etc.

Causes of Delay

Fixed Delay occurs primarily at intersections. This delay is not a result of the flow characteristics of the traffic stream and could occur with only one vehicle traveling the section. It may be caused for example, by traffic signals, stop signs, yield signs, or railroad crossings.

Operational Delay is the result of influences by other traffic.

- ✓ One type of operational delay is caused by other traffic movements that interfere with their stream flow (side friction), e.g. parking or unparking vehicles, turning vehicles, pedestrians, stalled vehicles, double parking, or cross traffic.
- ✓ The second type of operational delay is caused by internal frictions within the stream flow.

Methods for Obtaining Travel Time or Delay Data

Test Car Technique

The Test Car Technique utilizes a test vehicle which is driven over the street section in a series of runs.

- ✓ *The Floating Car Method*. In this method the driver tries to “float” in the traffic stream passing as many vehicles as pass the test car.
- ✓ *The Average Speed Method*. In this method the driver is instructed to travel at a speed that is judged to be representative of the speed of all traffic at the time.
- ✓ *Data Obtained* from the test car technique frequently includes delay information.
- ✓ *Equipment Used* in recording the data varies.
- ✓ An observer with one or two stopwatches was a common method but has generally been replaced by new technology. The observer starts the first watch at the beginning of each run, and records the time at various control points along the route. The second watch (if used) measures the length of individual

stopped-time delays. The time, location, and cause of these delays are recorded either on data forms or by voice recording equipment.

- ✓ Various recording devices have been developed to eliminate the necessity of using two persons on test runs. These include recording speedometers, tachometers, and the Traffic Stream Analyzer.
- ✓ State of the practice techniques involve using a GPS and will be discussed in Chapter 5.
- ✓ *Analysis*. The mean, standard deviation, and standard error of the mean of a series of test car runs and the significance of differences of the means of "before" and "after" studies are calculated.

License Plate Technique

The License Plate Technique is used when only travel-time information is desired.

Bluetooth Technologies

The tracking of Media Access Control (MAC) addresses via Bluetooth signals has emerged as a technology that offers space mean speed (segment detection) metrics. Many devices such as smartphones, headsets, and in-vehicle navigation systems are Bluetooth enabled and can be read by roadside readers. The MAC address of a device resembles a "license plate" for the particular device. Several vendors have developed platforms that can detect and record these addresses with timestamps in real-time. This information is then used to determine the travel time and delay along the route.

Intersection Delay Studies

Delay at intersections is a major problem in the analysis of congestion. Delay studies at individual intersections are valuable in evaluating the efficiency or effectiveness of a traffic control method. Other factors include crashes, cost of operation, and motorists' desires.

Factors which affect delay at intersections include:

- ✓ Physical factors such as number of lanes, grades, widths, access control, turning provisions, transit stops, etc.
- ✓ Traffic factors such as volume on each approach, driver characteristics, turning movements, pedestrians, parking, approach speeds, etc.

Methods for Measurement of Intersection Delay

- ✓ There are three measures of prime importance for describing intersection performance.
- ✓ Approach delay per vehicle is considered to be the best single measure. However, it must be derived indirectly from the stopped delay field study.
- ✓ Stopped delay per vehicle results directly from the field study. A multiplier factor is applied to the raw data to bring the estimate closer to the true value.
- ✓ Percent of vehicles stopping is a third performance measure. Again, a multiplication factor is applied to the raw field data to achieve a better estimate of the true value.
- ✓ Past and current procedures used to estimate or measure intersection delay fall into one of four basic categories.
- ✓ Point sample is based on a systematic sample of some factor (such as the number of stopped vehicles).
- ✓ Input-output uses an interval sample to measure some factor at both its point or time of beginning and ending.
- ✓ Path trace procedures track individual vehicles while noting their actions. The use of test cars as in travel time studies is a type of path trace.
- ✓ Models take into account the arrival and departure characteristics of vehicles, and many models incorporate some field measurements and data in the delay estimates.

- ✓ Field data collection consists of two items.
- ✓ Stopped delay obtained by a point sample procedure was found to be the most practical method for measuring intersection delay in the field. A minimum sample of 60 measurements of the number of vehicles in the approach

HCM Method for Direct Measurement of Prevailing Saturation Flow Rates

[Source: Highway Capacity Manual]

The Highway Capacity Manual (HCM) describes a technique for quantifying the base saturation flow rate for local conditions. In this manner, it provides a means of calibrating the saturation flow rate calculation procedure to reflect driver behavior at a local level. The technique is based on a comparison of field-measured saturation flow rate with the calculated saturation flow rate for a common set of lane groups at intersections in a given area.

Concepts

The default ideal saturation flow rate used in the methodology of Chapter 16 of the HCM is 1900 pc/h/ln. This value must be adjusted for prevailing traffic conditions such as lane width, left turns, right turns, heavy vehicles, grades, parking, parking blockage, area type, bus blockage, and left turn blockage. As an alternative to this adjustment to the "assumed" ideal saturation flow rate, the prevailing saturation flow rate may be measured in the field.

Saturation flow rate is the maximum discharge rate during the green time. It is usually achieved after about 10 to 14 seconds of green, which corresponds to the front axle of the fourth to sixth passenger car crossing the stop line after the beginning of green.

The base saturation flow rate is defined as the discharge rate from a standing queue in a 12 foot wide lane that carries only through passenger cars and is otherwise unaffected by conditions such as grade, parking, and turning vehicles.

The base saturation flow rate is usually stable over a period of time for similar traffic conditions in a given community. Values measured in the same lane during repetitive weekday traffic conditions normally exhibit relatively narrow distributions. On the other hand, saturation flow rates for different communities or different traffic conditions and compositions, even at the same location, may vary significantly.

Measurement Technique (Two People)

1. **Recorder**
   a) Note the last vehicle in the stopped queue when the signal turns green.
   b) Describe the last vehicle to the Timer.
   c) Note which are heavy vehicles and/or turning vehicles.
   d) Record the time called out by the Timer.
2. **Timer**
   a) Start stop watch at the beginning of the green and notify the Recorder.
   b) Count aloud each vehicle in the queue as its rear axle crosses the stop line.
   c) Call out the time for the fourth, tenth, and the last vehicle in the queue.
   d) Notify the Recorder, if queued vehicles are still entering the intersection at the end of the green.

Example

a) Take the difference in time between the 4th and last vehicle and divide by the number of vehicles served (seconds/veh).
b) The prevailing saturation flow rate is:

3600/ seconds/veh in a = veh/h/ln

	run #																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
time between 4th and last veh in queue	26	27	36	36	21	22	50	46	21	24	27	11	28	44	30		
# of veh between 4th and last in queue	12	13	16	21	11	9	24	27	10	12	8	9	14	26	15		
	2.17	2.08	2.25	1.71	1.91	2.44	2.08	1.70	2.10	2.00	3.38	1.22	2.00	1.69	2.00	2.05	s/veh
																1757	veh/h/ln
what if the recorder was 1 sec high	27	28	37	37	22	23	51	47	22	25	28	12	29	45	31		
	12	13	16	21	11	9	24	27	10	12	8	9	14	26	15		
	2.25	2.15	2.31	1.76	2.00	2.56	2.13	1.74	2.20	2.08	3.50	1.33	2.07	1.73	2.07	2.13	s/veh
																1694	veh/h/ln
what if the recorder was 1 sec low	25	26	35	35	20	21	49	45	20	23	26	10	27	43	29		
	12	13	16	21	11	9	24	27	10	12	8	9	14	26	15		
	2.08	2.00	2.19	1.67	1.82	2.33	2.04	1.67	2.00	1.92	3.25	1.11	1.93	1.65	1.93	1.97	s/veh
																1825	veh/h/ln

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3 LOCAL INTERSECTION CONCEPTS

3.1 Signal Timing Theory

Signalized intersections play a critical role in the safe and efficient movement of vehicular and pedestrian traffic. The objective of traffic signal timing is to assign the right-of-way to alternating traffic movements in such a manner to minimize the average delay to any group of vehicles or pedestrians and reduce the probability of crash producing conflicts. Some of the guiding standards to accomplish this objective are as follows:

In theory, short cycle lengths typically yield the lowest overall average delay. Additional items must be considered in the determination of the cycle length, such as, minimum time for vehicle and pedestrian movements and systems operations.

- ✓ Minimize the number of phases that are used. Each additional phase increases the amount of lost time due to starting delays and clearance intervals.
- ✓ Short cycle lengths typically yield the best performance in terms of providing the lowest overall average delay, provided the capacity of the cycle to pass vehicles is not exceeded. ***The cycle length, however, must allow adequate time for vehicular and pedestrian movements***. Longer cycles are used during peak periods to provide more green time for the major street, to permit larger platoons in the peak direction, and/or to reduce the number of starting delays.

Cycle Length

The cycle length is the total time to complete one sequence of signalization around an intersection. In an actuated controller unit, a complete cycle is dependent on the presence of calls on all phases. In a pre-timed controller unit (see page 3-5) it is a complete sequence of signal indications.

One approach to determining cycle lengths for an isolated pre-timed location is based on Webster's equation for minimum delay cycle lengths. The equation is as follows:

$$C_o = \frac{1.5\,tL + 5}{1.0 - \Sigma Y_i}$$

Where: C_o = Optimum cycle length in seconds

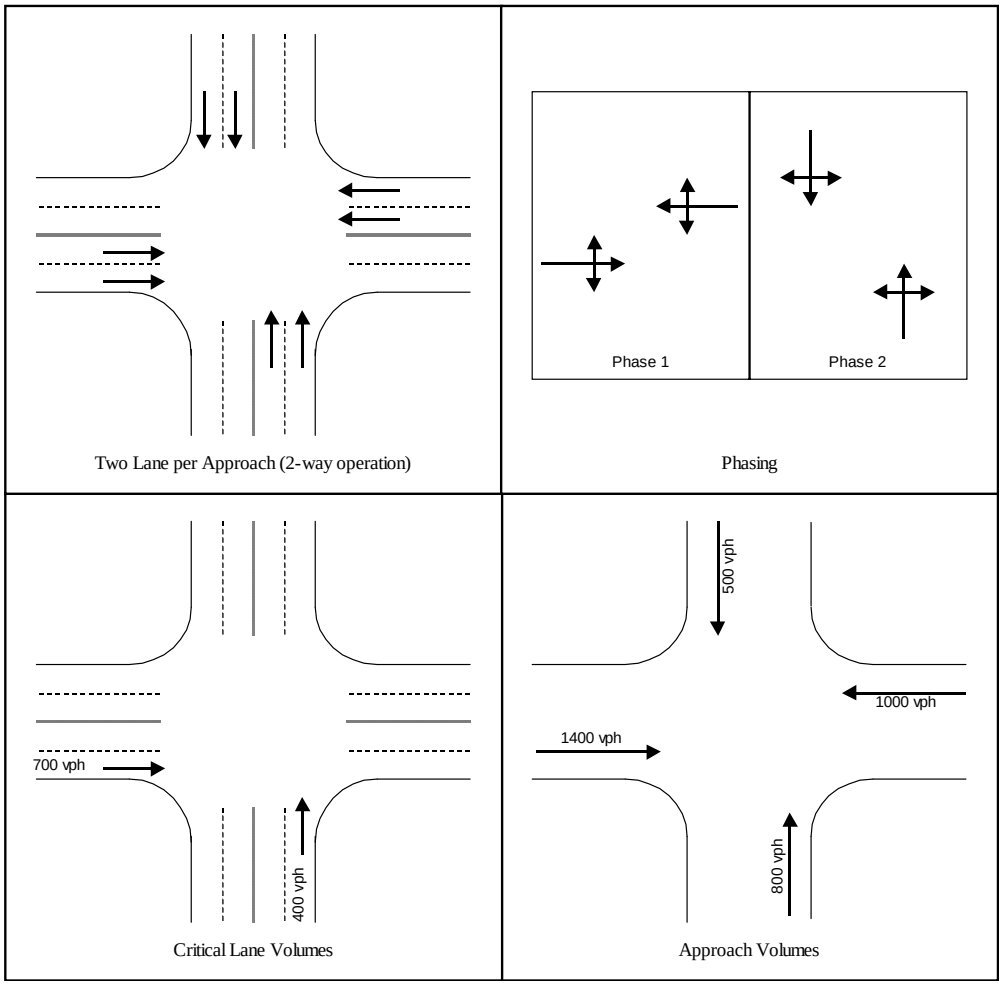
tL = The unusable time per cycle in seconds

$\sum Y_i$ = degree of saturation for Phase i

The equation above indicates that cycle lengths in the range of $0.75C_o$ to $1.5C_o$ do not significantly increase delay.

The equation is for isolated pre-timed signal locations only. A detailed network analysis should be performed using a software package such as TRANSYT 7-F or Synchro for cycle length determination in a coordinated system. The use of computer models allows for multiple iterations of varying cycle combinations to determine the optimum signal timing parameters. Chapter 5 of this manual will address this issue.

Example **:** Consider the intersection shown in the figure below. Assume the adjusted saturation flow rate is equal to 1700 vph, and the lost time per phase is 5 seconds.



Y_i = Observed Flow ÷ Saturated Flow

Y_1 = 700 ÷ 1700 = 0.412

Y_2 = 400 ÷ 1700 = 0.235

$\sum Y_i$ = 0.412 + 0.235 = 0.647

tL = unusable time per cycle = (2 phases) x (5 seconds lost per cycle)

= 10 seconds

$$C_o = \frac{1.5\ tL + 5}{1.0 - \Sigma Y_i} = \frac{1.5\ (10) + 5}{1.0 - 0.647} = 56.7 \text{ seconds, use 57 seconds}$$

3.2 Signal Timing Intervals and Splits

An **interval** is that portion of the cycle that signal indications do not change. There are several commonly termed intervals: minimum green, pedestrian clearance, yellow clearance, and all red. Timing parameters are applied to intervals (in other words, we can "time" the intervals).

The sum of the green, yellow, and all red intervals typically defines an individual phase **split**. A split is then the segment of the cycle length allocated to each phase that may occur (expressed in percent or seconds).

The primary considerations that must be given to vehicle split times are as follows:

- ✓ The phase duration must be no shorter than some absolute **minimum time**, such as five to seven seconds of green plus the required clearance interval. If pedestrians may be crossing with this phase, their crossing time must also be considered and included in the minimum phase length.
- ✓ A phase must be long enough to avoid over saturating any approach associated with it. Too short a time will cause frequent **cycle failures** where some traffic fails to clear during its phase.
- ✓ A phase length must not be so long that green time is wasted and vehicles on other approaches are delayed needlessly.
- ✓ Phase lengths should be properly designed to efficiently balance the cycle time available among the several phases, not just "equitably" between, say, north-south and east-west.

The distribution of the green time for a pre-timed signal should be proportional to the **critical lane volumes** on each phase (critical lane analysis is discussed on page 3-61). The formula for determining green time for a two-phase pre-timed intersection is as follows:

G_t (net green time) = $C - Y_1 - Y_2 - nl$

Where,

C = Optimum cycle length (see page 3-1).

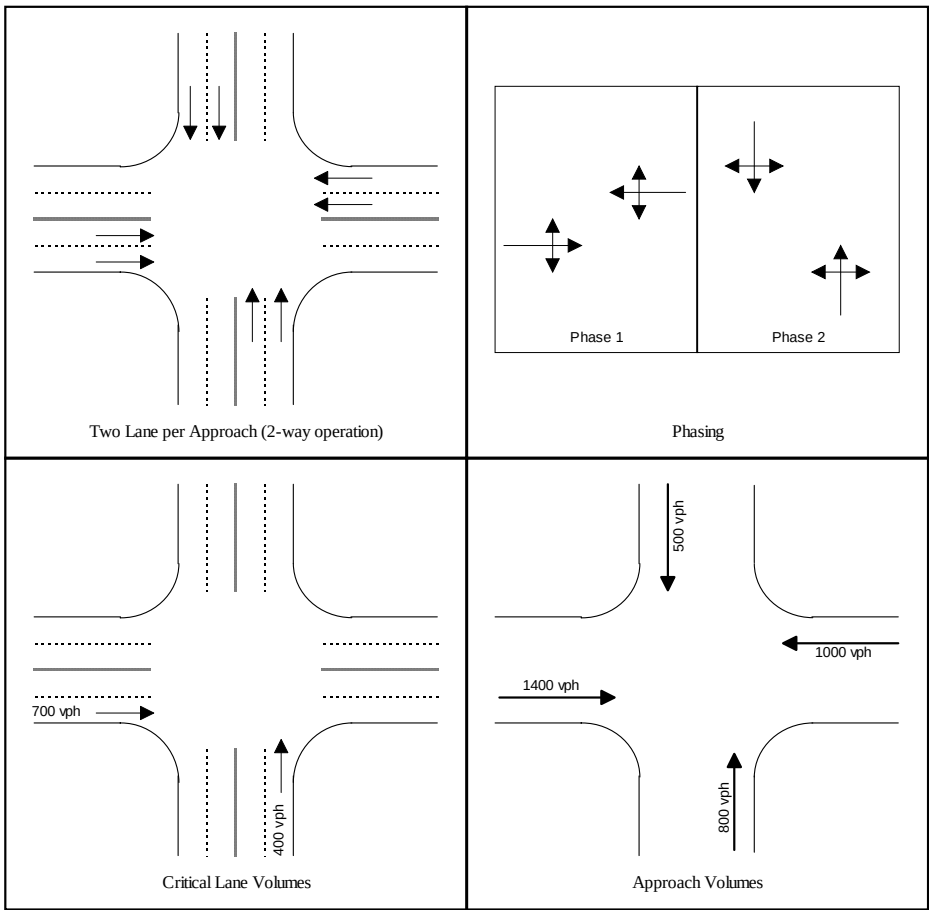
Y_1 = Yellow time on Phase 1, seconds

Y_2 = Yellow time on Phase 2, seconds

n = number of phases

l = Lost time per cycle, seconds

Example: Once again, consider the intersection shown in the following figure. Assume the lost time per phase is 5 seconds.



The Cycle length calculated is 57 seconds.

Assume yellow change time, $Y_1 = Y_2 = 5$ seconds.

Then,

$G_t = C - Y_1 - Y_2 - nl = 57 - 5 - 5 - 2(5) = 37$ seconds.

And,

Critical lane volumes = 700 + 400 = 1,100

$G_1 = 37 * 700 / 1{,}100 = 23.5$ seconds

$G_2 = 37 * 400 / 1{,}100 = 13.5$ seconds

Signal timing would then be as follows:

Phase 1 = 23.5 seconds green + 5 seconds yellow + lost time

= 33.5 seconds

Phase 2 = 13.5 seconds green + 5 seconds yellow + lost time

= 23.5 seconds

Cycle = Phase 1 + Phase 2 = 33.5 (59%) + 23.5 (41%) = 57 seconds

3.3 Signal Timing and Phasing

Controller Unit Timing

A traffic signal controls traffic by assigning right-of-way to one traffic movement or several non-conflicting traffic movements at a time. Right-of-way is assigned by turning on a green signal for a certain length of time or an interval. Right-of-way is ended by a yellow change interval during which a yellow signal is displayed, followed by the display of a red signal. The device that times these intervals and switches the signal lamps is called a controller unit. This section will cover the operation of controller units and the various features and characteristics of the types currently available.

Control Concepts

Traffic control concepts for isolated intersections basically fall into two basic categories, pre-timed and traffic-actuated.

Pre-timed signal control

Under these conditions, the signal assigns right-of-way at an intersection according to a predetermined schedule. The sequence of right-of-way (phases), and the length of the time interval for each signal indication in the cycle is fixed. No recognition is given to the current traffic demand on the intersection approaches unless detectors are used. The major elements of pre-timed control are (1) fixed cycle length, (2) fixed phase length, and (3) number and sequence of phases.

Advantages to pre-timed control include:

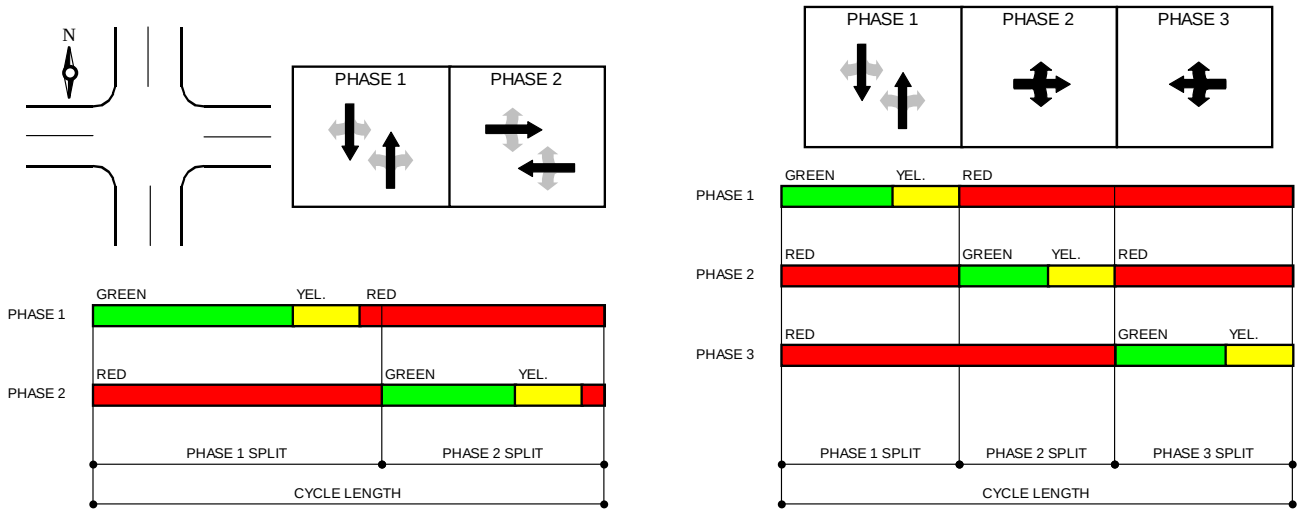
- ✓ Simplicity of equipment provides relatively easy servicing and maintenance.
- ✓ Can be coordinated to provide continuous flow of traffic at a given speed along a particular route, thus providing positive speed control.
- ✓ Timing is easily adjusted in the field.
- ✓ Under certain conditions can be programmed to handle peak conditions.

Disadvantages to pre-timed control include:

- ✓ Do not recognize or accommodate short-term fluctuations in traffic.
- ✓ Can cause excessive delay to vehicles and pedestrians during off-peak periods.

The left side of the following figure shows the timing operation for a basic two-phase or two-traffic movement pre-timed controller unit. The right side of the figure shows the timing operation for a three phase pre-timed controller unit. For the pre-timed controller, the length of time for each phase is fixed.

Exhibit 3-1 Basic Two-Phase Pre-timed Signal Operation



Traffic-actuated signal control

Traffic-actuated control attempts to adjust green time continuously, and, in some cases, the sequence of phasing. These adjustments occur in accordance with real-time measures of traffic demand obtained from vehicle detectors placed on one or more of the approaches to the intersection. The full range of actuated control capabilities depends on the type of equipment employed and the operational requirements.

Advantages to actuated signals include:

- ✓ Usually reduce delay (if properly timed).
- ✓ Adaptable to short-term fluctuations in traffic flow.
- ✓ Usually increase capacity (by continually reapportioning green time).
- ✓ Provide continuous operation under low volume conditions as an added safety feature, when pre-timed signals may be put on flashing operation to prevent excessive delay.
- ✓ Especially effective at multiple phase intersections.

Disadvantages to actuated control include:

- ✓ The cost of an actuated installation is higher than the cost of a pre-timed installation.
- ✓ Actuated controllers and detectors are much more complicated than pre-timed signal controllers, increasing maintenance and inspection skill requirements and costs.
- ✓ Detectors are costly to install and require careful inspection and maintenance to ensure proper operations.

Traffic actuated signal control can further be broken into the following categories:

Semi-Actuated Control. In semi-actuated control, the major movement receives green unless there is a conflicting call on a minor movement phase. The minor phases include any protected left-turn phases or side street through phases. Detectors are needed for each minor movement. Detectors may be used on the major movement if dilemma zone protection is desired.

In semi-actuated coordinated systems (referred to as Actuated Coordinated in Synchro), the major movement is the “sync” phase. Minor movement phases are served only after the sync phase yield point and are terminated on or before their respective force off points. These points occur at the same point in time during the background signal cycle and ensure that the major road phase will be coordinated with adjacent signal controllers.

In semi-actuated non-coordinated systems, the major movement phase is placed on minimum (or maximum) recall. The major movement rests in green until a conflicting call is placed. The conflicting phase is serviced as soon as a gap-out or max-out occurs on the major phase. Immediately after the yellow is presented to the major phase, a call is placed by the controller for the major phase, regardless of whether or not a major phase vehicle is present.

Full Actuated Control. In full actuated control, all signal phases are actuated and all signalized movements require detection. Generally used at isolated intersections; however, can also be used at high-demand intersections in coordinated systems.

Volume-density operation can be considered to be a more advanced form of full-actuated control. It has the ability to calculate the duration of minimum green based on actual demand (calls on red) and the ability to reduce the maximum allowable time between calls from passage time down to minimum gap. Reducing the allowable time between calls below the passage time will improve efficiency by being better able to detect the end of queued flow.

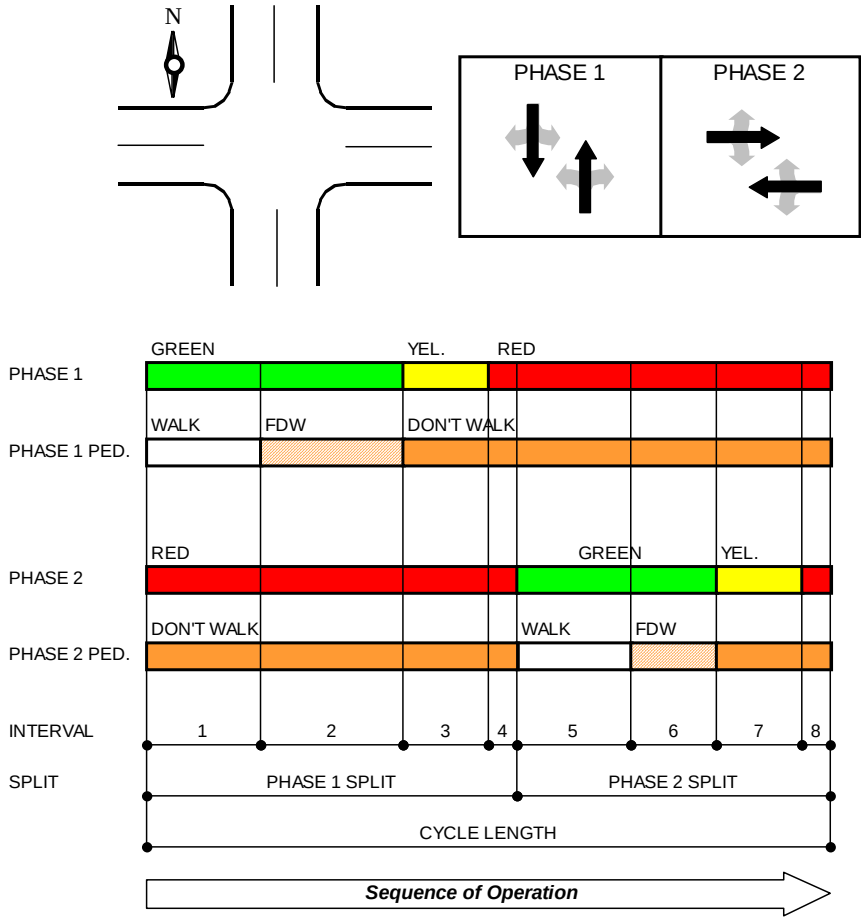
Traffic Signal Phasing

A traffic **signal phase**, or **split**, is the part of the cycle given to an individual movement, or combination of non-conflicting movements during one or more intervals. An **interval** is a portion of the cycle during which the signal indications do not change.

The predetermined order of phases is the sequence of operation. This order is fixed in a pre-timed controller, and under certain circumstances, may be variable with an actuated controller.

Consider **Exhibit 3-2** for an example two-phase (single ring) signal with pedestrian timing. In the figure, there are eight intervals where the signal indications do not change. Notice that intervals 4 and 8 are all red periods (interval 4 is the phase 1 all red and interval 8 is the phase 2 all red). The phase 1 split is made up of intervals 1 through 4 and the phase 2 split is made up of intervals 5 through 8. The sum of split 1 and 2 is the cycle length.

Exhibit 3-2 Traffic Signal Phasing



Ring and Barrier Structure

Ring

A ring is a term that is used to describe a series of conflicting phases that occur in an established order. A ring may be a single ring, dual ring, or multi-ring and is described in detail below. A good understanding of the ring structure is a good way to understand the operation of multiphase controllers.

Barrier

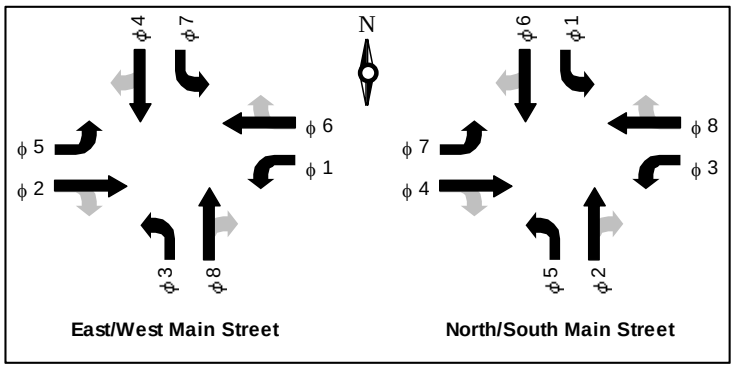
A barrier (compatibility line) is a reference point in the preferred sequence of a multi-ring controller unit at which all rings are interlocked. Barriers assure there will be no concurrent selection and timing of conflicting phases for traffic movements in different rings. All rings cross the barrier simultaneously to select and time phases on the other side.

Phase Numbers

Phase numbers are the labels assigned to the individual movements around the intersection. For an eight phase dual ring controller (see definition of dual ring), it is common to assign the main street through movements as phases 2 and 6. Also, it is common to use odd numbers for left turn signals and the even numbers for through signals. A rule of thumb is that the sum of the through movement and the adjacent left turn is equal to seven or eleven.

Exhibit 3-3 shows a typical phase numbering scheme for an east/west arterial and a north/south arterial.

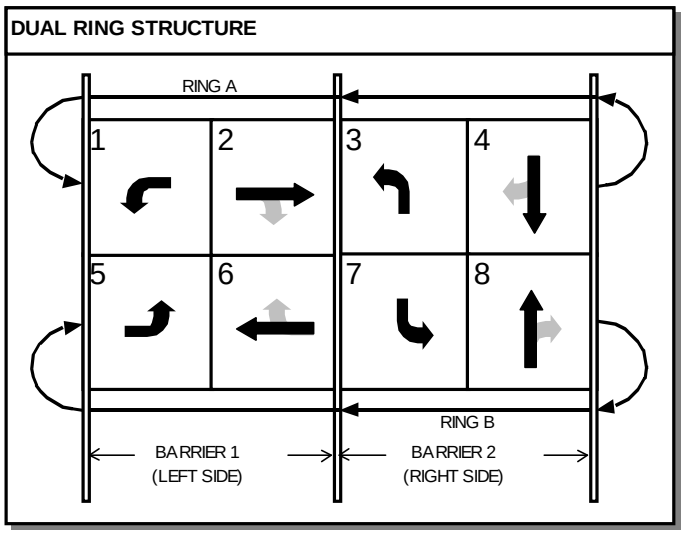
Exhibit 3-3 Common Phase Numbering Scheme



Dual Ring Control

By contrast to the pre-timed controller unit, the traffic actuated controller usually employs a "dual ring concurrent" timing process. The NEMA concept is illustrated in **Exhibit 3-4**.

Exhibit 3-4 Dual Ring Control



The dual-ring controller uses a maximum of eight phase modules, each of which controls a single traffic signal face with red, yellow and green display. The eight phases are required to accommodate the eight movements (four through and four left turns) at the intersection. Phases 1 through 4 are included in ring 1, and phases 5 through 8 are included in ring 2. The two rings operate independently, except that their control must cross the "barrier" at the same time.

If the movements to be controlled by these eight phases are assigned properly, the controller will operate without giving the right-of-way simultaneously to conflicting movements. All of the movements from one street (usually the major street) must be assigned to the left side of the barrier. Similarly, all movements from the other street must be assigned to the right side.

On both sides of the barrier there are four movements (two through and two left). Each of the four may proceed without conflict with two of the other three. So if the left turn in any given direction is placed in ring 1 along with its opposing through movement, and the remaining two movements are placed in ring 2, it will be possible for either movement in ring 1 to be displayed simultaneously with either movement in ring 2 without conflict.

The dual-ring concurrent operation can be shown to maximize the operating efficiency at an intersection by eliminating the "slack" time on each cycle (i.e., control will follow one or the other of the two paths shown).

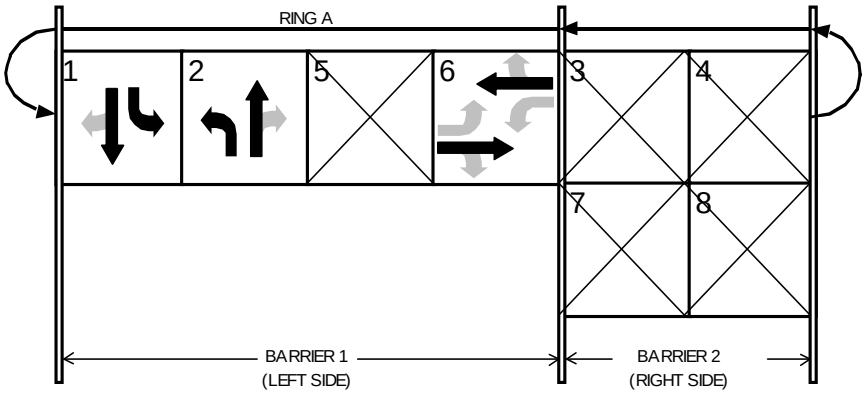
Modern controllers offer more flexibility in assigning traffic signal phases in order to control many complex or unique situations. TS2 controllers include four timing rings and up to sixteen vehicle phases and sixteen pedestrian phases. Each phase can be assigned to any ring. In addition, there are up to sixteen overlap assignments.

Single Ring (Sequential Phases)

Sometimes it is desirable to use a single ring and have the phases operate one at a time sequentially. Each phase is individually timed and can be skipped if there is no demand for it. This is called sequential or exclusive phasing. When using sequential phases on the left side of the barrier, phases 1-2-5-6 show in order. When using sequential phases on the right side of the barrier, phases 3-4-7-8 show in order.

Exhibit 3-5 is an example of a controller using Sequential phases. North and South traffic use split phasing, East and West share a phase.

Exhibit 3-5 Sequential Phasing



Multi-Rings and Barriers

A controller supporting more than eight phases and two rings would be a multi-ring controller. Any number of phases, up to the maximum supported by the controller, can be arranged in any number of rings. Conflicts between phases in different rings are specified using either barriers inserted between groups of phases, or phase concurrency lists. Exhibit 3-6 illustrates 16 phases in a quad-ring / quad-barrier structure.

Exhibit 3-6 Multi-Ring Phasing

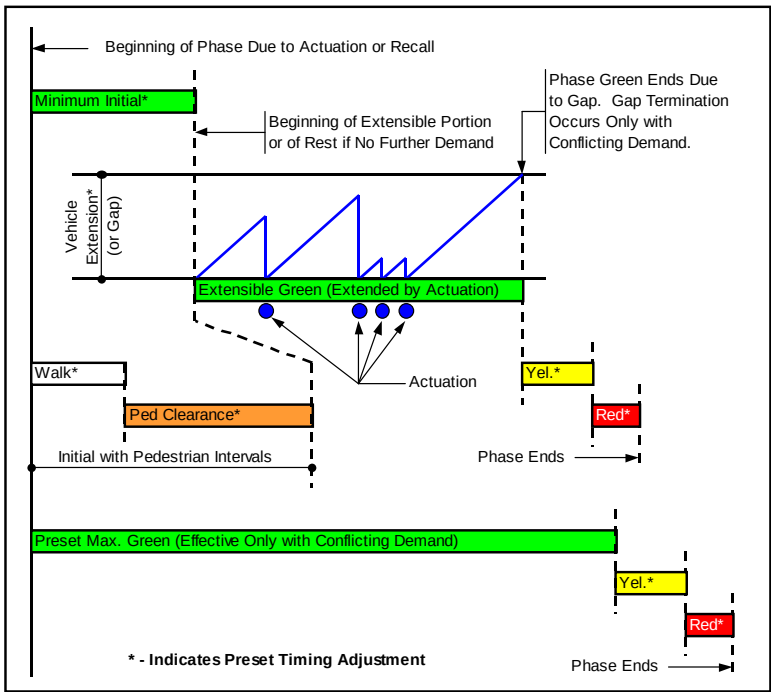
	Barrier 1				Barrier 2				Barrier 3				Barrier 4			
Ring 1	Phase 1	Phase 2			Phase 3	Phase 4			Phase 9	Phase 10			Phase 11	Phase 12		
Ring 2	Phase 5	Phase 6			Phase 7	Phase 8			Phase 13	Phase 14			Phase 15	Phase 16		
Ring 3																
Ring 4																

Phasing Parameters

Some of the basic principles of timing the green interval in a traffic actuated controller unit are as follows:

- ✓ There must be a **minimum green** time so that a stopped vehicle that receives a green signal has enough time to get started and partially across the intersection before the yellow signal appears. This time is termed the **initial portion** of the green interval.
- ✓ Each following vehicle requires green time. This is called **passage time**, **vehicle extension,** or **gap**. Gap refers to the distance between vehicles as well as the time between vehicles.
- ✓ There must be a **maximum time** that the green interval can be extended if opposing cars are waiting - this is called **extension limit** or **maximum**.
- ✓ A timing diagram for one traffic actuated phase is shown in the figure that follows. The other phase or phases operate in the same manner.
- ✓ The number of "presets" is the number of timing adjustments in the **extensible portion**. Each detector actuation starts the unit extension timing again. With no opposing calls the controller rests. Unit extensions continue being timed, but with no effect on the green interval.
- ✓ However, once an **actuation** is received from an opposing phase, unit extension is used to expedite servicing that phase as follows: if the time between actuations is greater than the preset unit extension or gap the extensible portion will be ended, the yellow change interval will appear and the next phase in sequence with demand will receive the right-of-way. This is called termination by gap or **gap-out**.
- ✓ An actuation from another phase received in any portion of the green interval also starts another timing circuit. This is called the extension limit or maximum green. Even if actuations are close enough in time to prevent gap termination, the maximum limit will terminate the green interval when the preset maximum expires. This is called termination by maximum green or **max-out**.

Exhibit 3-7 Traffic Actuated Phase Timing Diagram



Minimum Green

The Minimum Green Interval is the shortest green time of a phase. If a time setting control is designated as "minimum green," the green time shall be not less than that setting. For MnDOT practice on minimum green (minimum initial) times, refer to page 4-7.

Initial Intervals

There are three types of initial intervals as follows:

- ✓ Extensible initial
- ✓ Added initial
- ✓ Computed initial

Extensible initial is the method of calculating the variable initial period commonly used in field practice. This method adds the time specified as "seconds per actuation" to the minimum initial (green) for each vehicle actuation received by a phase during the yellow and/or red signal (depending on red and yellow lock) up to a maximum initial time. This method is common in both 170 and NEMA controllers.

Added initial is similar to extensible initial with the exception that the "seconds per actuation" calculation does not begin until a user specified number of vehicles actuations have occurred. The added initial option is generally used when long minimum green times are specified.

Computed initial calculates the amount of time given to each vehicle actuation (computed seconds per actuation) during the red signal display of the phase based on the following formula:

(Maximum initial interval time) ÷ (number of actuations that can be serviced during the minimum initial interval) x (number or recorded actuations). The total time allowed for the computed initial interval is limited by both the minimum green and maximum initial interval.

Passage Time

Passage Time (also referred to as vehicle extension or gap time) is the time that the phase will be extended for each actuation. Passage time is typically set as the time it takes to travel from the vehicle detector to the stop line at the travel speed of the roadway for pulse loops or the average acceptable headway between vehicles for presence loops located close to the stop line. Therefore, the vehicle extension is related to the minimum and maximum gap. For MnDOT practice on passage time refer to page 4-18.

Maximum Green

Depending on the type and manufacturer of the controller being simulated, there can be two methods for calculating the maximum amount of green time allowed per phase. Method 1 or maximum green, allows the user to input the maximum amount of green time a phase will be allowed to be active, (i.e. display green.) The max. timer in the controller begins its countdown at the receipt of a conflicting vehicle or pedestrian call, generally the beginning of phase green and includes any minimum green or variable initial period.

Method 2, maximum green extension, is the amount of time a phase will be allowed service after the minimum green and variable initial have timed out. While some controller manufacturers still allow maximum green extension, it is more commonly found in older isolated NEMA and Type 170 controllers. Assuming that vehicle headways remain less than the vehicle extension time during the green signal display of the phase, Method 1 will always produce the same timing value. However, in Method 2 the total green time is not only dependent on vehicle headways during the phase green but also on the number of vehicles that arrive during the red display for the calculation of variable initial. Therefore, total green time for Method 2 can vary from cycle to cycle irrelevant of vehicle headways.

If the controller is operating within a coordinated system the maximum green time specified in the controller may not be appropriate for the cycle/split combination selected by the master controller. In this case the phase can max-out early without ever reaching the force-off point (the end of the assigned phase split) for the phase.

Note: In certain manufacturers' controllers, there will be a timing function called "MAX EXT." This is not the same as maximum extension green but the number of seconds used to extend the maximum green value when "MAX 3" is active.

For MnDOT practice on maximum green times, refer to page **4-20**.

Pedestrian Phasing

Because pedestrians move at a slower speed than vehicles, they require different treatment of the green interval. A pedestrian actuation, therefore, results in more green time than would be allowed for a vehicle: a "Walk" interval followed by a flashing "Don't Walk" pedestrian clearance. In the absences of opposing calls, succeeding pedestrian actuations will recycle the pedestrian indications.

- ✓ Pedestrian intervals result in a green interval for the parallel vehicle phase or phases. **Exhibit 3-7** on the page **3-11** shows the timing diagram for pedestrian operation.
- ✓ It is also possible to have an exclusive pedestrian phase. That is, no vehicle green intervals will occur. All pedestrian signals at an intersection could be controlled by this phase.

Red Vehicle Clearance

Red clearances (ALL RED) is the safety clearance interval at the end of a phase that displays red for all traffic movements. For MnDOT practice on red clearance intervals see page **4-23**.

Recall

Normally a controller unit will, in the absence of actuation, rest on the last phase serviced. By means of a recall switch the controller unit can be forced to return to a particular phase's green interval, even with no demand.

Every phase has the capability of operation with the following types of recall:

- ✓ *Minimum Recall*. When active and in the absence of a vehicle call on the phase, a temporary call to service the minimum initial time will be placed on the phase. If a vehicle call is received prior to the phase being serviced the temporary call will be removed. Once the phase is serviced it can be extended based on normal vehicle demand.
- ✓ *Maximum Recall.* With the maximum vehicle recall active a constant vehicle call will be placed on the phase. This constant call will force the controller to time the maximum green. Maximum recall is generally used to call a phase when local detection is not present or inoperative.
- ✓ *Pedestrian Recall.* This feature provides vehicle green and pedestrian walk and clearance intervals. After that, normal green timing is in effect except that pedestrian calls will not recycle pedestrian intervals until opposing phases are serviced.
- ✓ In addition, a phase has a vehicle call placed on it if it is terminated with some passage time remaining. This can happen with termination by maximum.
- ✓ If all of the active phases of a controller unit are placed on recall the controller unit will operate in a pre-timed mode. It should be added that unless the detectors are disconnected from a phase, that phase's green interval could be extended beyond the preset minimum if the recall is to minimum.

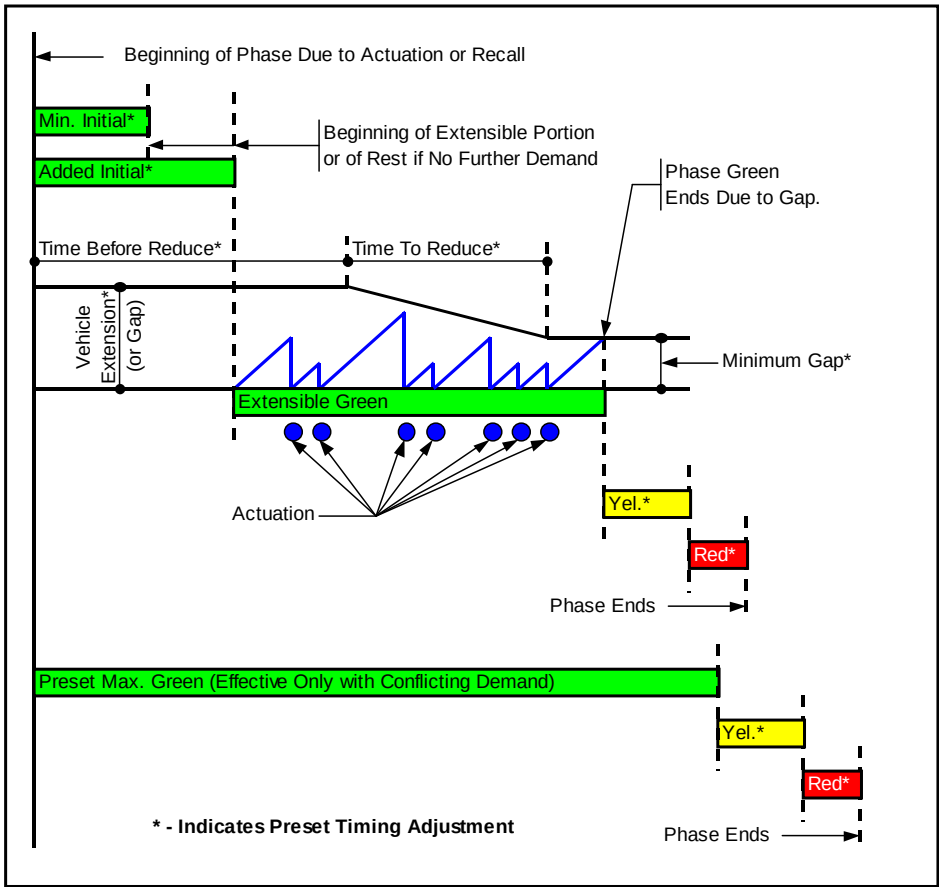
Volume Density Control

Even more sophisticated operation is possible with the volume density traffic actuated controller unit. In addition to the features discussed above, volume density provides two means of modifying the basic timing intervals. These are:

- ✓ *Variable initial* is a means of extending the initial portion of the green interval. This is done on the basis of the number of actuations above a preset number while the phase is displaying yellow or red. This extended initial provides additional green time for a queue of vehicles waiting, when the green signal appears, to clear the intersection if the detectors are set back a distance from the stop bar and there are no vehicles following.
- ✓ *Gap reduction* is a means of reducing the passage time or gap on the basis of the time that opposing vehicles have waited. In effect, it benefits the waiting vehicles by reducing the time allowed between vehicles arriving on the green phase before that phase is terminated.

The timing diagram for a volume density phase is shown in **Exhibit 3-8**.

Exhibit 3-8 Volume-Density Timing Diagram



Gap Reduction

Gap reduction, as the name implies, reduces the gap or allowable headways between vehicles from the original value (MAX GAP) to a lesser value (the MIN GAP) over a specified amount of time.

While gap reduction is used sporadically in the field, it can be a valuable tool. For example, assume there is an approach to a fully actuated intersection that experiences a very sluggish “start-up” creating excessive headways until vehicles are moving at a more normal speed. If the gap is set where it should be for the

normal speeds, the phase would constantly gap-out early. If, however, the gap were set to accommodate the start-up vehicles, the phase would run to maximum green more times than necessary. This problem could be handled by providing a long minimum green time or extending the vehicle call but would also contribute to an inefficient signal operation. By providing a longer than normal vehicle extension (gap) time at the beginning of the signal phase and then reducing the gap to a more reasonable value during the vehicle start-up time the problem is relieved with little or no effect on efficiency. Similarly, gap reduction can take care of the problems experienced at intersections with large fluctuations in traffic volumes during the day. Generally these intersections have low vehicular volumes with long vehicle headways during off-peak travel times and shorter headways during peak travel periods. Gap reduction techniques could provide a longer gap at the beginning of the phase when volumes are low, headways are long, and an overall shorter cycle length is provided. The gap would then be reduced to a lesser value as volumes increase, headways decrease, and the cycle length increases.

Three types of gap reduction include:

Reduce by/reduce every

The user can specify that the gap can be reduced by a specified amount for every user specified interval. (Older Type 170 controllers only allow this option.)

Reduce by every second

The user can specify the gap will be reduced by a given amount of time every second.

Time to reduce to minimum gap.

The user can specify the gap will be reduced from its original value (vehicle extension) or maximum value (maximum gap) to a minimum value (minimum gap) over a user specified amount of time. (This method of gap reduction is commonly used in field conditions and allowed by all NEMA and newer model Type 170 controllers.)

Note: For any method of gap reduction in effect, the gap begins to be reduced at the receipt of a call on a conflicting phase. This is generally, but not always the beginning of phase green. NEMA and newer 170 controllers allow the user to specify an amount of time from the beginning of phase green until gap reduction begins. This value is called Time-Before-Reduction and is commonly used in the field when gap reduction is active.

For MnDOT practice of time to reduce and time before reduce see page **4-17**.

Minimum Gap

This input is the minimum acceptable vehicle gap specified by the user. It is also used to specify the end of the gap reduction period when the reduce by/reduce feature is selected.

For MnDOT practice on minimum gap see page **4-19**.

Maximum Gap

Maximum gap defines the gap at the beginning of the gap reduction period.

Yellow Lock

Most NEMA and Type 170 controllers use yellow lock as a factory standard setting that cannot be changed by the user. Some of the terms used to define this function are LOCK, or MEMORY on/off, or LOCKING MEMORY on/off, or a similar term and toggle. If this memory lock toggle is “on” (active) vehicle actuation which occur during the yellow and red display of the signal phase are accumulated and remembered in the controller and used in the variable initial calculation and/or to call the phase for service. If the toggle is set

to "off" (inactive) it only means the controllers does not remember or count vehicle actuation or place a call for service on a phase that has an unoccupied detector.

Double (Dual) Entry

When double (dual)-entry is permitted, a vehicle call on one phase, in the absence of a call on a compatible phase, will automatically place a call on the primary corresponding compatible phase. For example using the standard NEMA phase numbering scheme, assuming the intersection being considered is under light traffic conditions. A call for service is received on phase 2 but there are no other calls on phase 5 or 6. With dual entry active the call on phase 2 would automatically place a temporary call on phase 6. When phase 2 became active and no call was received on phase 5, phase 6 would be displayed simultaneously with phase 2. If a call had been received on phase 5 before phase 2 became active, the temporary call on phase 6 would have been removed and phases 2 and 5 would have been displayed. In the standard NEMA phase numbering scheme, compatible dual-entry phases are 1 and 5, 2 and 6, 3 and 7, and 4 and 8. If dual-entry is not active a vehicle call on a phase will only allow the display of that phase in the absence of a call on a compatible phase. The usage of dual-entry is generally a policy decision. However, common usage is to have dual entry active on the NEMA standard even-number phases (through movements) and inactive on NEMA standard odd-number phases (left-turn movements).

Rest in Red

While rest in red is a phase specific input, in actuality, it is used to designate when all phases of the controller are allowed to rest in red in the absence of calls or recalls on any phase. Therefore, if rest in red is set to active for any phase it should be active for all phases. In most controllers this is a per unit function and generally a toggle.

While this function is not uncommon, especially for isolated intersection with relative even traffic flows on all approaches, it is the more general practice to allow the controller to rest in green on the mainline approaches in the absence of calls. In this case, rest in red would be set to inactive for all phases.

Lag Phase

The lag phase setting designates which phase of a phase pair displays green first, or before the other phase. A phase pair is defined as adjacent phases in the same ring on the same side of the barrier on a standard NEMA phase diagram. Therefore, phase pairs are phases 1 and 2, 3 and 4, 5 and 6, and 7 and 8. Phase pairs are not NEMA compatible signal display phases such as 1 and 5, or 2 and 6.

In a standard NEMA 8 phase configuration operating in leading dual lefts on both streets, phases 2, 4, 6 and 8 are lag phases while phases 1, 3, 5, and 7 are leading phases. For a lead/lag sequence, phase 2 can lead, and phase 1 can lag. This will produce the signal display sequence of phases 2 and 5, then phases 2 and 6, then phases 1 and 6. It is also possible to have both left turns lagging by specifying phases 2 and 6 as leading and phases 1 and 5 as lagging. *Lagging left-turn phases are typically only used in coordinated systems.*

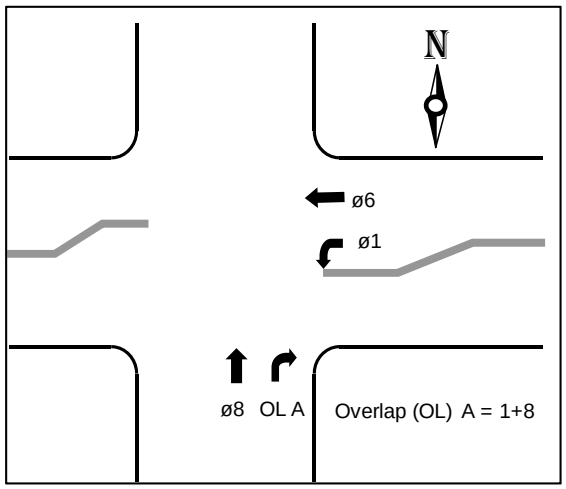
Overlap Phasing

An overlap is a right-of-way indication which allows traffic movement when the right-of-way is assigned to two or more traffic phases. An overlap occurs when one green signal indication is illuminated by more than one phase output from a controller.

Right Turn Overlap (Controller Programmed)

Refer to the exhibit below. In this case, the NBR is assigned as overlap A in the controller. The parent phases for OL A are 1 and 8.

Exhibit 3-9 Right Turn Overlap Phasing



For this case, the yellow ball and red clearance is NOT displayed and green arrow will continue to be displayed during change from phase 1 to 8.

Controller programming can omit the right turn arrow if there is a conflicting pedestrian call.

Note: Controller Programmed Overlap is preferred over Hardwired Overlap.

Right Turn Overlap (Hardwired)

Refer to the image on the right. For the hardwired overlap, the NBR is wired directly with the WBL.

For this case, the yellow ball and red clearance is displayed during change from phase 1 to 8.

This operation cannot be used if there is a conflicting pedestrian crossing.

The hardwired configuration is not typically used by MnDOT.

Overlaps with U-Turns

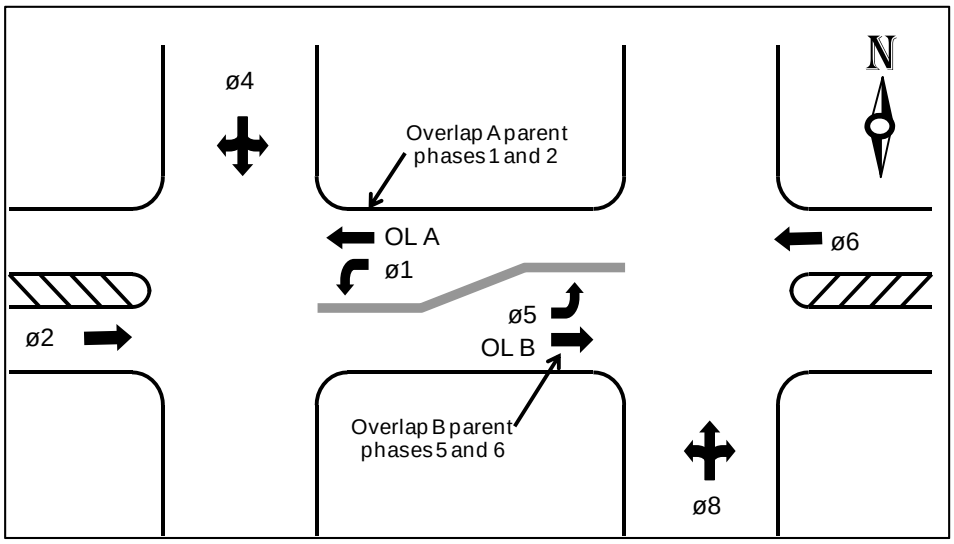
When a right turn overlap is used, consideration should be given to the conflicting U-turn (WB U-turn in the image above). In some instances, it might be necessary to prohibit U-turns. Another option is to use a “U-Turn Yield to Right Turn” sign.

Close Ramp Intersections Using Signal Controller with Overlaps

Refer to the image below. In this case, the WBT at the west ramp is assigned as overlap A in the controller. The parent phases for OL A are 1 and 2.

The EBT at the east ramp is assigned overlap B in the controller. The parent phases for OL B are 5 and 6.

Exhibit 3-10 Overlap Phasing



Red Revert

Under very light traffic conditions and fully actuated control it is possible without red revert active for a phase to go from green to yellow and then back to green without ever displaying a red indication. Red revert timing prevents this signal display sequence by forcing the red indication to be displayed after a yellow for at least the red revert time. Red revert in generally factory programmed at 2 seconds.

Phase Hold

During coordinated operation, a "hold" can be placed on user-selected phases to prevent these phases from terminating before their force-off point is reached. This is desirable when lead-lag left-turn phasing combinations are used to maximize two-way progression. Placing a "hold" on a lagging left-turn phase prevents that phase from premature "gap-out" and ensures that the phase does not terminate until its force-off point is reached. This prevents the concurrent through phase from terminating prematurely and shortening the progression band in that direction.

The lag phase hold input is commonly used in closed-loop systems that do not have local intersection vehicle detection. Once the phase is initialized, by either minimum recall or maximum recall, it will continue to display green not terminating until its force-off point is reached. All maximum green or vehicle extensions will be ignored if detection is used. This function should not be confused with the controller function "Inhibit Max Termination." The Inhibit Max termination function allows the controller to "gap-out" or be "forced-out" but not "max-out." The lag phase hold to force-out function will only allow the simulated controller to be "forced-out" and has no impact on controllers which are not operating within a coordinated system.

Simultaneous Gap-Out

Both NEMA and 170 operational logic specifies that both controller rings, ring 1 and ring 2, must cross the barrier at the same time. This can be accomplished by each of the phases 2 and 6 "gapping-out," "maxing-out," or "forcing-off." With simultaneous gap-out not active, one ring can gap-out and the other can max-out. Additionally, once a phase gaps-out it will stay in that condition, irrelevant of any future vehicle actuations until the phase in the opposite ring either gaps-out or maxes-out and then both phases cross the barrier. With simultaneous "gap-out" active, each of the phases cannot cross the barrier until both phases have been terminated in the same manner, by either "gap-out" or both "max-out." Additionally, if a phase initially "gaps-out" and then, due to increased vehicle demand, vehicle arrivals are less than the extension

time, the "gap-out" flag for that phase is removed. With simultaneous "gap-out" active, the vehicle headways on both phases must currently be exceeding the gap-in-effect. The inactive status for this function generally produces a quicker reacting signal and shorter cycle lengths.

Twice Per Cycle Left Turns

A common problem experienced during long cycle lengths is when the queue from a left-turn lane backs up into a through lane and reduces the capacity of the through movement. Twice Per cycle Left-Turn (TPCLT) operation reduces this left-turn "spill-over" problem on an as needed basis by servicing the protected left-turn movement as a leading AND a lagging left-turn. This allows the left-turn bay to empty during the lead left-turn movement and recharge during the through movements before being serviced again as a lagging left-turn. TPCLT operation is even more effective for dual-left-turn lanes that are effectively reduced to a single lane when the spillback extends into the through lane of traffic.

TPCLT operation differs from conditional-service which only allows a protected left-turn phase to be re-serviced if the opposing through movement gaps out. TPCLT ensures that the lagging left-turn is serviced even during congested periods when the through phases are maxing out.

Conditional Service

When a heavy left-turn demand exists at an intersection (generally not coordinated), it may be desirable to service one of these left-turn phases twice in the same controller cycle. The conditional service entry, under a specific set of circumstances, allows the left to be serviced first as a leading phase and then as a lag phase. Specifying this feature will allow the controller to operate in this manner under the following circumstances:

- ✓ There is a call for service on a leading left-turn phase.
- ✓ The controller is operating in the non-coordinated mode.
- ✓ There is a conflicting call on the opposite side of the barrier. Otherwise the left-turn phase will automatically be serviced next by standard controller logic unless the anti-backup controller feature is active.
- ✓ The through phase of the phase pair with the left-turn call for service has gapped-out.
- ✓ The time remaining on the active through phase's maximum timer exceed the conditional service phase's minimum conditional service time. Conditional service time is generally equal to or greater than the minimum green of the left turn phase to be conditionally serviced.

3.4 Emergency Vehicle Preemption (EVP)

Emergency vehicle preemption (EVP) is a system installed on authorized emergency vehicles and at traffic signals which allows the authorized emergency vehicles to travel through signalized intersections in a safe and timely manner.

The system works as follows:

- ✓ An authorized emergency vehicle approaching a signalized intersection enroute to a call has an activated emitter (an infrared LED or a visible strobe light oscillating at a specified frequency).
- ✓ The oscillations are detected by an EVP detector mounted on the signal mast arm.
- ✓ The detector may be located elsewhere to increase the range.
- ✓ The signal controller terminates any conflicting phases to bring up the through phase for the authorized emergency vehicle.
- ✓ Indicator lights mounted on the mast arm indicate that preemption is in operation.

Care must be taken when considering the operation of EVP with permissive left turns (see page **3-20** for a discussion on permissive left turns) to prevent left turn trapping (see page **3-29**). Using EVP with a flashing yellow arrow will prevent the trap problem as discussed on page **3-31**.

Transit Signal Priority

Bus priority or transit signal priority (TSP) is a name for various techniques to improve service and reduce delay for mass transit vehicles at intersections (or junctions) controlled by traffic signals. TSP techniques are most commonly associated with buses, but can also be used along streetcar, tram, or light rail lines that mix or conflict with general vehicular traffic.

Transit signal priority techniques can generally be classified as active or passive. Passive TSP techniques typically involve optimizing signal timing or coordinating successive signals to create a "green wave" for traffic along the transit line's route. Passive techniques require no specialized hardware (such as bus detectors and specialized traffic signal controllers) and rely on simply improving traffic for all vehicles along the transit vehicle's route.

Active TSP techniques rely on detecting transit vehicles as they approach an intersection and adjusting the signal timing dynamically to improve service for the transit vehicle. Unlike passive techniques, active TSP requires specialized hardware: the detection system typically involves a transmitter on the transit vehicle and one or more receivers (detectors), and the signal controller must be "TSP capable", i.e. sophisticated enough to perform the required timing adjustments. This operation requires special coordination programming of the controller that is separate from EVP and regular coordination programming.

Active strategies include:

- ✓ **Green Extension**: This strategy is used to extend the green interval by up to a preset maximum value if a transit vehicle is approaching. Detectors are located so that any transit vehicle that would just miss the green light ("just" meaning by no more than the specified maximum green extension time) extends the green and is able to clear the intersection rather than waiting through an entire red interval.
- ✓ **Early Green (aka red truncation)**: This strategy is used to shorten the conflicting phases whenever a bus arrives at a red light in order to return to the bus' phase sooner. The conflicting phases are not ended immediately like they are for emergency vehicle preemption systems but are shortened by a predetermined amount.
- ✓ **Early Red**: If a transit vehicle is approaching during a green interval, but is far enough away that the light would change to red by the time it arrives, the green interval is ended early and the conflicting phases are served. The signal can then return to the transit vehicle's phase sooner than it otherwise would. Early red is largely theoretical and is not commonly used in practice.
- ✓ **Phase Rotation**: The order of phases at the intersection can be shuffled so that transit vehicles arrive during the phase they need.
- ✓ **Actuated Transit Phase(s)**: These are phases that are only called if a transit vehicle is present. These might be seen along streetcar lines or on dedicated bus lanes.
- ✓ **Phase Insertion**: This strategy allows a signal controller to return to a critical phase more than once in the same cycle if transit vehicles that use that phase are detected.

3.5 Left Turn Phasing

There are five options for the left-turn phasing at an intersection: permissive only, protected only, protected-permissive, split phasing, and prohibited. Phasing can have a significant impact on signal system effectiveness for a number of reasons, including:

- ✓ Permissive only left turn operation may reduce delay for the intersection, but may adversely affect intersection safely, because it requires motorists to choose acceptable gaps.
- ✓ Protected only left-turn phases may reduce delay for turning vehicles but are likely to increase overall intersection delay.
- ✓ Protected-permissive left turn phases can offer a good compromise between safety and efficiency but could limit available options to maximize signal progression during coordination unless innovative displays are used.
- ✓ Split phasing may be applicable with shared lanes, but could increase coordinated cycle length if both split phases are provided a concurrent pedestrian phase.
- ✓ Prohibited left turns may be used selectively to reduce conflicts at the intersection.

Protected and Permissive Left Turn Phasing

If a protected left turn phase is to be used (left turn made without conflicts with opposing traffic) left turns may or may not also be permitted on a circular green or Flashing Yellow Arrow (see page 3-24) indication with opposing traffic.

In general, it is desirable to allow this permissive left turn movement unless there are overriding safety concerns which make such phasing particularly hazardous.

- ✓ Use of a permissive left turn can significantly reduce overall intersection delay as well as delay to left turners.
- ✓ Use of permissive left turn phasing may reduce the required length of left turn storage on the approach and allow an approach with substandard left turn storage to operate more efficiently.

Certain situations exist where safety considerations generally precluded the use of permissive left turns. In these cases, left turns should be restricted to the exclusive left turn phases. Such situations include:

- ✓ Intersection approaches where crash experience or traffic conflicts criteria are used as the basis for installing separate left turn phasing.
- ✓ Blind intersections where the horizontal or vertical alignment of the road does not allow the left turning driver adequate sight distance to judge whether or not a gap in on-coming traffic is long enough to safely complete his turn.
- ✓ High-speed and/or multilane approaches may make it difficult for left turning drivers to judge gaps in oncoming traffic. Such locations should be evaluated on an individual basis.
- ✓ Unusual geometric or traffic conditions may complicate the driver's task and necessitate the prohibition of permissive left turns. An example of such conditions is an approach where dual left turns are provided.
- ✓ When normal lead-lag phasing is used (due to left turn trapping).

Some of the issues noted above that preclude the use permissive left turns may only be applicable during certain times of the day. Traditionally, this would require protected only operation for the entire day. The use of the FYA display (see page 3-24) would allow the indication to operate as protected only during some times of the day and permissive or protected/permissive during others. The use of the FYA display can also eliminate the left turn trapping problem that is discussed in the next section.

Left Turn Phasing Sequence

A critical element to the operation of a traffic signal is the determination of the appropriate phasing sequence. At signalized intersections where traffic volumes are heavy or speeds are high, vehicles attempting to turn left across opposing traffic may constitute significant safety and capacity problems. Based on this, there are additional considerations for determining the left turn phasing alternative. These include:

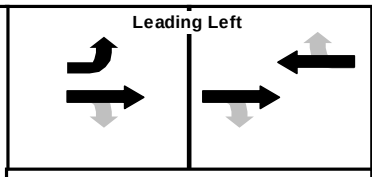
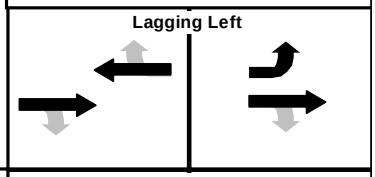
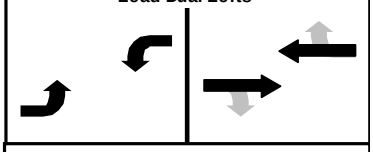
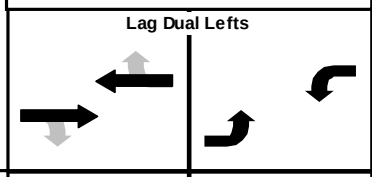
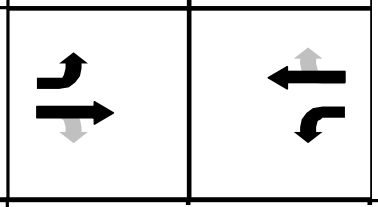
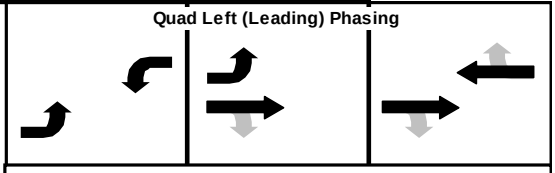
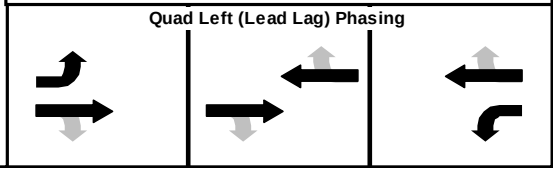
- ✓ *Heaviest Left Turn Protected* - This is a leading left phase scheme in which the left-turning vehicles from only one approach are protected and move on an arrow indication proceeding the opposing through movement; or a lagging left when the protected left turn follows the through movement phase.
- ✓ *Both Left Turns Protected (Without Overlap)* - When the opposing left turns move simultaneously followed by the through movements, it is called a "lead dual left". If the left turns follow the through movement, it is called a "lag dual left".
- ✓ *Both Left Turns Protected (With Overlap)* - In this operation, opposing left turns start simultaneously. When one terminates, the through movement in the same direction as the extending left movement is started. When the extended left is terminated, the remaining through movement is started. When this type of phasing is used on both streets, it is termed "quad left phasing".
- ✓ *Lead Lag* - This phasing is combined with a leading protected left in one direction, followed by the through movements, followed by a lag left in the opposing direction. It is sometimes used in systems to provide a wider two-way through band.
- ✓ *Directional Separation (Split)* - First, one approach moves with all opposing traffic stopped, then the other approach moves with the first approach stopped.

Exhibit 3-11 shows the above basic left turn phasing schemes.

Whether or not separate left turn phasing should be provided is a decision that must be based on engineering analysis. This analysis may involve serious trade-offs between safety, capacity, and delay considerations.

- ✓ Separation of left turns and opposing traffic may reduce crashes that result from conflicts between these movements, and may increase left turn capacity. However, through traffic capacity may be reduced.
- ✓ Left turn phasing may reduce peak period delay for left turners, but may increase overall intersection delay. Off-peak left turn delay may also increase.

Exhibit 3-11 Left Turn Phasing

Heaviest Left Turn Protected This is a leading left phase scheme in which the left-turning vehicles from only one approach are protected and move on an arrow indication proceeding the opposing through movement; or a lagging left when the protected left turn follows the through movement phase.	**Leading Left**  **- OR -** **Lagging Left** 
Both Left Turns Protected (Without Overlap) When the opposing left turns move simultaneously followed by the through movements, it is called a "lead dual left". If the left turns follow the through movement, it is called a "lag dual left".	**Lead Dual Lefts**  **- OR -** **Lag Dual Lefts** 
Directional Seperation (Split) First, one approach moves with all opposing traffic stopped, then the other approach moves with the first approach stopped.	
Both Turns Protected (with Overlap) In this operation, opposing left turns start simultaneously. When one terminates, the through movement in the same direction as the extending left movement is started. When the extended left is terminated, the remaining through movement is started. When this type of phasing is used on both streets, it is termed "quad left phasing". ***Lead Lag*** phasing is combined with a leading protected left in one direction, followed by the through movements, followed by a lag left in the opposing direction. It is sometimes used in systems to provide a wider two-way through band. .	**Quad Left (Leading) Phasing**  **- OR -** **Quad Left (Lead Lag) Phasing** 

3.6 Flashing Yellow Arrow Display

The Flashing Yellow Arrow (FYA) head is a signal that uses a flashing yellow arrow indication for permissive left turns instead of using a green ball. A 7-year national study determined that the 4-section FYA signal head with a red arrow on top, followed by a steady yellow arrow, a flashing yellow arrow, and then a green arrow on the bottom was the best and safest type of left-turn signal head based on driver confirmation and field implementation studies.

The FYA head is now the recommended left turn head in the Federal 2009 Manual of Uniform Traffic Control Devices (MUTCD). This version of the MUTCD includes language on the use of the flashing yellow arrow for permitted left turns that states:

> "Vehicular traffic, on an approach to an intersection, facing a flashing YELLOW ARROW signal indication, displayed alone or in combination with another signal indication, is permitted to cautiously enter the intersection only to make the movement indicated by such arrow, or other such movement as is permitted by other signal indications displayed at the same time.
>
> Such vehicular traffic, including vehicles turning right or left or making a U-turn, shall yield the right-of-way to:
>
> a) Pedestrians lawfully within an associated crosswalk, and
> b) Other vehicles lawfully within the intersection.
>
> In addition, vehicular traffic turning left or making a U-turn to the left shall yield the right-of-way to other vehicles approaching from the opposite direction so closely as to constitute an immediate hazard during the time when such turning vehicle is moving across or within the intersection."

MnDOT does encourage the use of FYA whenever appropriate. Additional details on the FYA can be found by visiting:

http://www.dot.state.mn.us/trafficeng/signals/flashingyellowarrow.html

http://mutcd.fhwa.dot.gov/resources/interim_approval/ia_10_flashyellarrow.htm

http://www.fhwa.dot.gov/publications/research/safety/09036/index.cfm

Refer to Page **3-26** for a handout technical memo on the use of the FYA in Minnesota.

3.7 Minnesota Flashing Yellow Arrow

The section on "**Flashing Yellow Arrow Display**" in the previous section discusses the FYA from a national and Federal MUTCD perspective. The following sections discuss the use of the FYA within Minnesota.

The discussions in this section "Minnesota Flashing Yellow Arrow" are current at the time of printing this publication. However, the items mentioned are anticipated to be continually changing. Please be sure to constently check the MnDOT website for updates (See www.dot.state.mn.us/trafficeng/).

Variable vs. Fixed Phasing Operation Signal Heads

Traditionally, the operation of the left turn signal was considered fixed. That is, if a protected left turn head was installed, then this signal would operate in protected operation for the entire day. It may be that a protected left is desirable for a specific time of day (i.e., heavy opposing flow is the reason for the protected operation), but this may "penalize" the other twenty-three hours of the day that do not require protected-only operation. One advantage to

the FYA signal indication is that it can change the mode of operation on a time of day (TOD) basis. In summary:

- ✓ The FYA head is a "variable phasing operation" head that can operate with either protected, protected/permissive, or permissive phasing operation by time-of-day settings.
- ✓ Standard 3-section protected and 3-section permissive heads are "fixed phasing operation" heads that can only operate in one phasing operation 24 hours a day.
- ✓ Given that the FYA head can operate protected 24 hours a day, if desired, the standard 3-section protected head will soon become obsolete as there is no reason to install a 3-section protected head and not have the ability to change the phasing operation in the future.
- ✓ Standard 5-section heads are "flexible phasing operation" heads, but only with either protected/permissive or permissive operation by time-of-day settings.

Use of the Flashing Yellow Arrow Signal Head

New Signal Design

All agencies should consider using a FYA in their design of new signals with exclusive left turn lanes. However, it's still acceptable to use a 3-section protected or 5-section protected/permissive head for new signal installations. Designs should conform to the Federal and MN MUTCDs. The 2009 Federal MUTCD no longer allows a green circular permitted signal indication centered over an exclusive left turn lane (see the Federal MUTCD Section 4D.13).

Even if a left turn movement may <u>never</u> have a high enough left-turn volume to run protected/permissive, consider using a FYA head for exclusive left turn lanes as it gives flexibility in case volumes increase in the future, and it also gives a clearer message to left turning vehicles that they must yield to opposing traffic when turning left.

The incremental increase in cost of a 4-section FYA signal head is insignificant in the overall cost of the new signal. In fact, the 4-section signal head may be less expensive than the 5-section protected/permissive signal head.

Retrofit Signal Design

An existing signal with exclusive left turn lanes may be retrofitted with FYA operation. Consideration should take into account the type of cabinet, controller, loop detection, and mast arm locations when retrofitting a signal for FYA. This issue is currently under development by MnDOT and more information is forthcoming. Refer to the MnDOT Traffic Signal Design manual for additional details.

When Not to Operate a FYA Permissive Indication

Under certain situations, the FYA indication should not be used in permissive mode, even if the 4-section FYA head is in place.

A. Opposing Left Turn Paths Conflict

- ✓ Road design will be responsible for noting on signal design plan that opposing left turns conflict by running AutoTurn and cannot be allowed to turn at the same time.

B. Very Limited Sight Distance

- ✓ Sight distance is so limited that a left turn cannot be made safely even under very low volume conditions

C. Shared Left/Through Lane(s)

- ✓ The concept of using a Flashing Yellow Arrow head on approaches with shared left-turn/through lanes is under development, but is currently only recommended for experimental use and more information is forthcoming (see the section "**MnDOT Website and Contacts**" shown below if considering this type of operation).

In addition, see the sections below regarding FYA use with pre-emption (emergency vehicle and railroad).

Use of FYA Sign on Mast Arm

The national FYA study determined that the FYA is the best type of head for understanding by motorists. However, because it is a new operation, an optional FYA sign stating "Left Turn Yield on Flashing Yellow Arrow" may be used as a temporary educational message. This federal MUTCD states that this sign must not include any symbols.

- ✓ MnDOT's current practice is to install this sign for a minimum of 6 months and it may be removed after 6 months at the discretion of the traffic engineer.

MnDOT Website and Contacts

The latest information on the use of the FYA in Minnesota can be found at the following website:

www.dot.state.mn.us/trafficeng/signals/flashingyellowarrow.html

For additional information, or to discuss experimental use of the FYA, contact:

- ✓ Jerry Kotzenmacher
- ✓ Phone: 651-234-7054
- ✓ E-mail: jerry.kotzenmacher@state.mn.us

The discussions in the above section "Minnesota Flashing Yellow Arrow" are current at the time of printing this publication. However, the items discussed are anticipated to be continually changing. Please be sure to constently check the MnDOT website for updates.

Flashing Yellow Arrow Technical Memorandum

The information on the following page is a handout from Technical Memorandum No. 12-10-T-03. The purpose of the technical memorandum is to require the installation of the flashing yellow arrow (FYA) left turn indication on all new traffic signal dedicated left turn lane approaches on the State trunk highway system unless the left turner has limited intersection sight distance (as defined in Chapter 9, Table 9–14 of the 2011 AASHTO "A Policy on Geometric Design of Highways and Streets"), or conflicting (i.e. overlapping) left turn paths are present.

HANDOUT

MINNESOTA DEPARTMENT OF TRANSPORTATION
Engineering Services Division
Technical Memorandum No. 12-10-T-03
November 28, 2012

To: Electronic Distribution Recipients

From: Jon M. Chiglo, P.E.
Division Director, Engineering Services

Subject: Flashing Yellow Arrow Traffic Signal Indication on MnDOT Trunk Highways

Expiration
This is a new Technical Memorandum and will remain in effect until November 28, 2017 unless it is superseded by a new Technical Memorandum or included in the MnDOT Traffic Engineering Manual.

Implementation
This policy shall be effective immediately.

Introduction
The purpose of this technical memorandum is to require the installation of the flashing yellow arrow (FYA) left turn indication on all new traffic signal dedicated left turn lane approaches on the State trunk highway system unless the left turner has limited intersection sight distance (as defined in Chapter 9, Table 9–14 of the 2011 AASHTO "A Policy on Geometric Design of Highways and Streets"), or conflicting (i.e. overlapping) left turn paths are present.

The National Cooperative Highway Research Program (NCHRP) Report 493 has shown the flashing yellow arrow indication is more understandable and operationally more efficient than traditional protected/permissive left turn indications such as a 5-section indication. MnDOT's experience since the first such installation in 2006 confirms the study results. It has also proved to be significantly more operationally efficient than the protected-only left turn indication. The 2011 Minnesota Manual on Uniform Traffic Control Devices (MnMUTCD), Section 4D.20, explains the definition, placement and operation of the flashing yellow arrow indication. The 2011 MnMUTCD has also changed the head placement for a green ball, which is no longer allowed over the center of a dedicated left turn lane.

The traditional Protected Permissive Left Turn (PPLT) Guidelines are still provided in the 2012 Signal Design Manual for agencies that have not adopted the FYA. When operated properly by time of day, the flashing yellow arrow can be used in many situations where protected-only phasing had been the only operational option. If conflicting left turn paths are present, the signal must be operated in a split-phase operation, and it should be noted on the plan to be sure the signal operator is aware of the conflicting lanes. Documented sight distance issues should also be noted on the plans.

Purpose
To provide additional safety and operational efficiency at traffic signals using a flashing yellow left turn arrow.

Guidelines

Policy
This policy refers to all signals on the trunk highway system. This includes both mainline and cross-street dedicated left turn lanes. A 4-section head using a red arrow, yellow arrow, flashing yellow arrow and green arrow shall be used. Any agency doing work on the trunk highway system shall install the flashing yellow arrow for dedicated left turn lanes on all signal designs for new and reconstructed signal installation with the following exceptions.

HANDOUT

- If a sight distance deficiency is documented per definition above, the flashing yellow arrow should not be installed.
- The flashing yellow arrow should not be installed when there are conflicting left turn paths.
- If it has been determined that the signal will run protected only based on engineering judgment related to multiple turn lanes, high volumes and high speeds (all three present), a traditional protected-only 3-section red, yellow, green arrow indication may be used in place of the flashing yellow arrow. If a flashing yellow arrow is not installed based on the above criteria, the system shall be designed to easily accommodate a change to a flashing yellow arrow in the future, including length of mast arm, wiring, cabinet and controller.

If the flashing yellow arrow is not installed at a location because it has conflicting left turn lanes or, a sight distance deficiency, or if there is other information that is important for the signal operator or future signal designer to be aware of, this information shall be provided by the signal designer on the signal plan. Additionally, if conflicting left turns are present, the signal must be operated split phase 24 hours a day or with conflicting left turns as “no serve phases”. If multiple turn lanes and high volumes exist and the posted speed is such that the signal will only be operated in a protected-only phase 24 hours a day, the installation of a protected-only 3-section signal head will be allowed. However, the flashing yellow arrow may still be installed under these conditions and operated in a permissive mode when conditions allow.

Consideration can be given to left turn lanes that have a shared use such as a shared left/thru lane or split-phase operation. This Technical Memorandum does not require the use of a flashing yellow arrow with a shared-use left turn lane or split-phase operations.

Consideration can also be given to existing signal revisions. Costs can be high for retrofitting the flashing yellow arrow into an existing signal; therefore signal revisions do not fall under this Technical Memorandum. Consideration may be given if signal design and operational components support the use of the flashing yellow arrow.

With the flashing yellow arrow indication, left turn operations can vary between protected, protected/permissive and permissive operations by time-of-day programming in the signal controller. It should be noted that, with the flashing yellow arrow, the operator must pay particular attention to how the signal is operated by time of day to achieve the highest level of efficiency and safety. Additional guidelines for the operation can be found in the 2011 MnDOT Traffic Signal Timing and Coordination Manual, page 3-24.

Scope
The policy contained in this technical memorandum applies to MnDOT roadways.

Questions
For information on the technical contents of this memorandum, please contact **Sue Zarling,** Traffic Electrical Systems Engineer at **(651) 234-7052** or **Jerry Kotzenmacher,** Signal Specialist at **(651) 234-7054**.

Any questions regarding publication of this Technical Memorandum should be referred to the Design Standards Unit, DesignStandards.DOT@state.mn.us. A link to all active and historical Technical Memoranda can be found at http://techmemos.dot.state.mn.us/techmemo.aspx.

To add, remove, or change your name on the Technical Memoranda mailing list, please visit the web page http://techmemos.dot.state.mn.us/subscribe.aspx

3.8 Left Turn Trapping

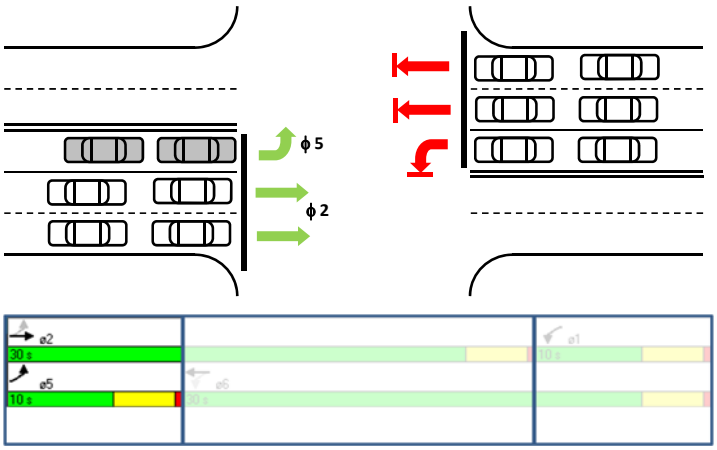
As noted earlier, the combination of a permitted left turns with lead-lag creates a situation commonly called the "left-turn trap" (when no FYA is used).

Consider **Exhibit 3-12** for an eastbound leading left scenario. There is no real problem with the westbound situation here; these left turners are presented in stage 2 with a green ball after a period of obvious opposing flow. It is clear they must yield to the eastbound through traffic. In stage 3 this movement is protected and, again three is no problem. The transition is given by green ball direct to green arrow, but even if a yellow ball was displayed at the end of stage 2, there is no problem.

The problem is with the eastbound left turns. If this scenario is allowed, any left turner who had not been able to find a gap during the stage 2 green would be presented with a yellow indication at its end. Since these drivers see a yellow indication on all facing displays (through and left), they may incorrectly presume that the westbound through is likewise receiving a yellow indication and is about to stop. When the signal turns red (eastbound) the turner will: 1) at best be stuck (now illegally), in the middle of the intersection with nowhere to go, or 2) at worst commit the left turn thinking the opposition is stopping creating a serious safety issue.

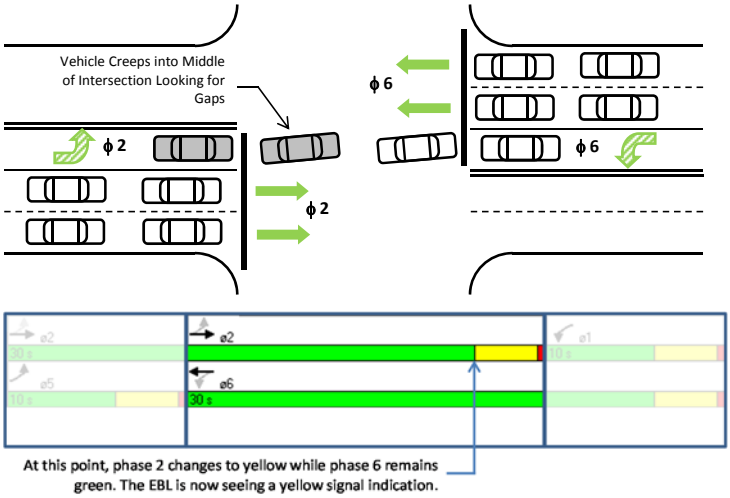
Refer to page **3-31** for information on how the flashing yellow arrow can eliminate the left turn trap condition.

Exhibit 3-12 Lead/Lag Left Turn Trap



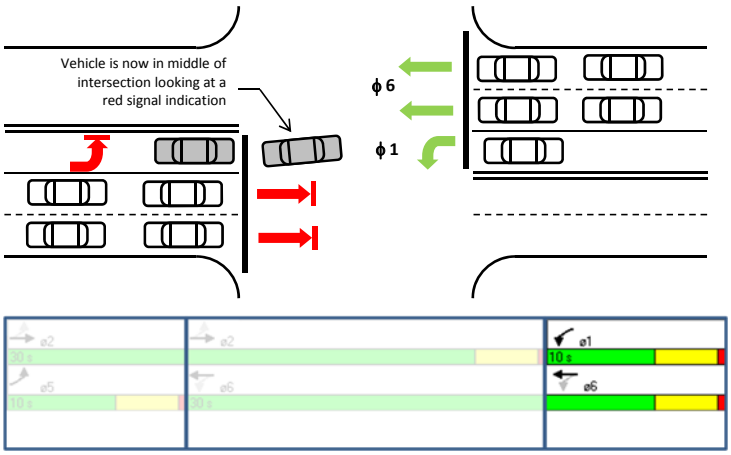
Stage 1: Phase 5 eastbound (EBL) shows a protected left turn arrow while phase 2 eastbound shows a green ball. The opposing WB movements are stopped.

No issues during this stage; the left turn vehicles have a protected movement.



Stage 2: The EBL and WBL now operate as permitted lefts (sees a green ball indication). During this stage, the EBL may creep into the middle of the intersection looking for gaps in the opposing traffic. Note that the EBL is actually operating as Phase 2 permitted.

At the end of this stage is when the problem occurs. Phase 2 indications will change to yellow. The EBL vehicle now has to consider how to clear the intersection and may falsely assume the opposing through is seeing a yellow indication and is about to stop. In fact, the WBT remains green since phase 1 WBL is up next.



Stage 3: Now, phase 1 WBL shows a green arrow (protected) operation while phase 6 WBT remains green. The EBL may have assumed the WBT was stopping and attempts to sneak through the intersections creating a crash situation.

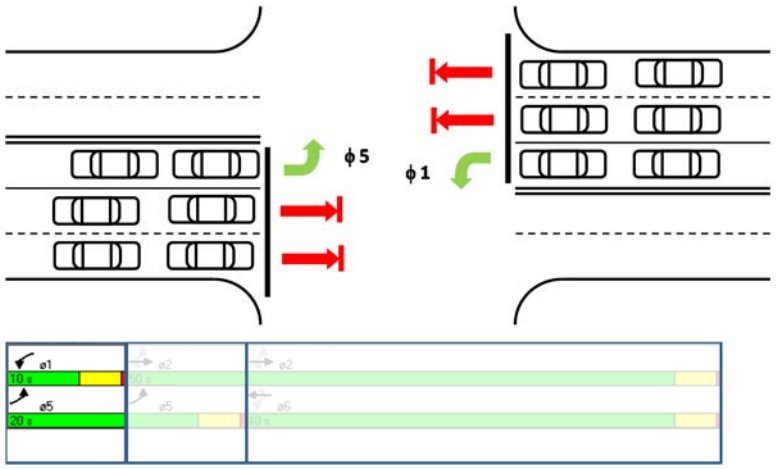
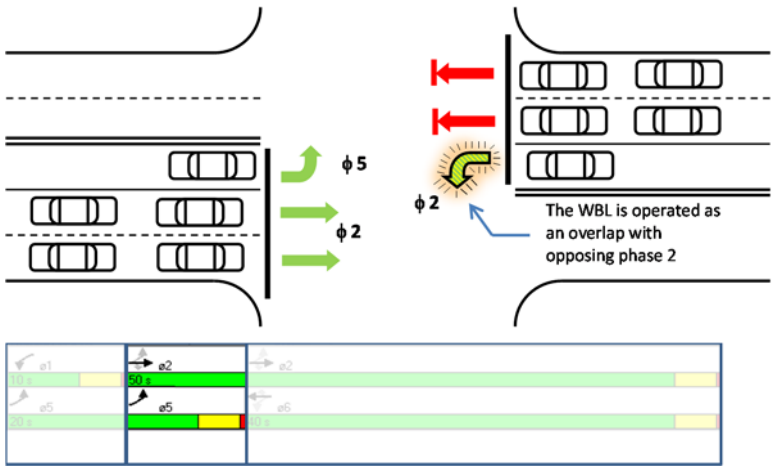
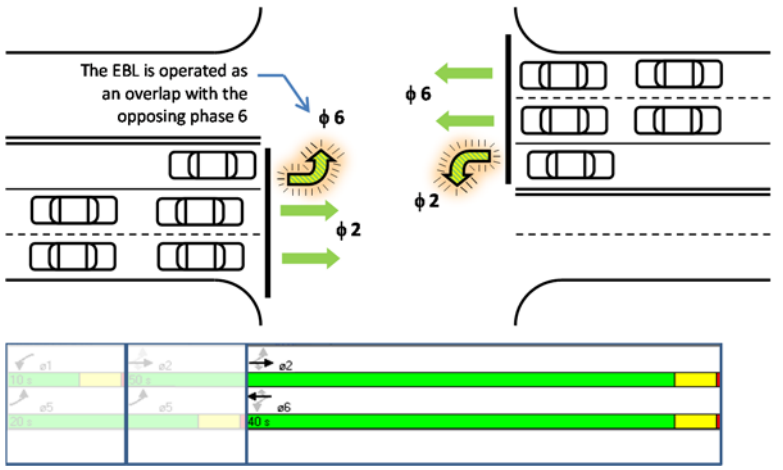
Flashing Yellow Arrow and the Left Turn Trap

Exhibit 3-12 illustrates a left turn trap with traditional lead/lag phasing (i.e., a green ball indication is used for the permitted left turns). Using a FYA indication can eliminate the trap condition illustrated in this exhibit.

Once again, consider the EBL vehicle. During stage 1, the EBL receives a green arrow and proceeds under the protected movement. During stage 2, the EBL shows the flashing yellow arrow indication and the movement operates as a permissive movement. In stage 3, the EBL remains a flashing yellow arrow indication instead of turning red. The EBL FYA actually operates as an overlap to phase 6. Therefore, the EBL and opposing WBT terminate at the same time as expected by the driver.

Exhibit 3-13 illustrates the signal operation of the FYA even under the "soft-trap" condition and how this can be eliminated.

Exhibit 3-13 FYA to Eliminate Left Turn Trap

	**Stage 1**: During this stage, normal leading protected and opposing left turn phases operate. This is the typical operation even with a traditional 5-section signal indication. At the end of this stage, phase 1 clears the intersection with a solid yellow arrow.
	**Stage 2**: During this stage phase 2 begins green as phase 5 continues green in normal operation. The opposing left turn is operated as a FYA. In a traditional 5-section operation, the opposing left turn would be red.
	**Stage 3**: In this stage, phase 2 and 6 throughs receive a green ball indication. The opposing lefts are operated as an FYA overlap with the opposing through. This will ensure that the left turn clears (turns yellow) and then red with the opposing through, thus eliminating the left turn trap.

3.9 Detection

The section discusses the functions available for traffic signal detectors. The design and layout of detectors at an intersection is discussed in the Traffic Signal Design Manual. Refer to page **3-38** for information from the Signal Design Manual.

Detector Labeling and Phase Assignments

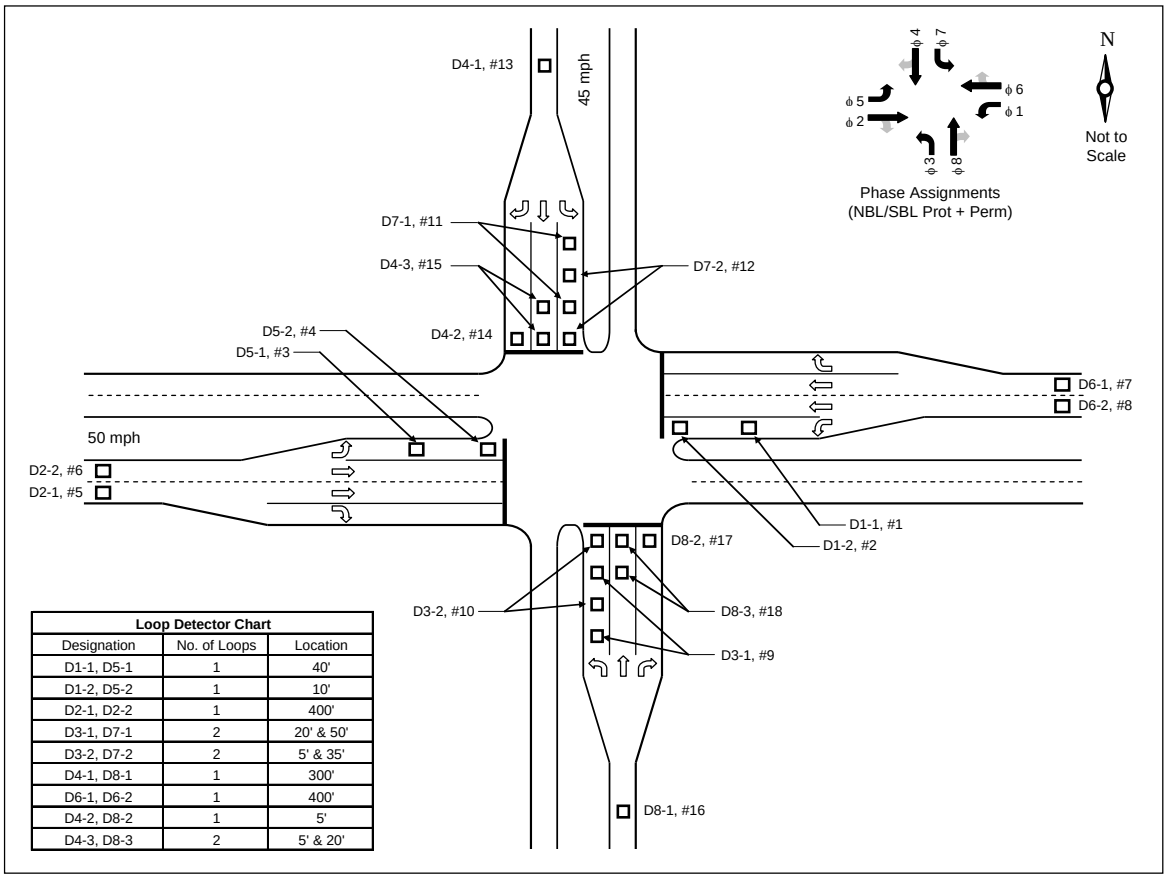
In loop detector design, detectors are labeled on the plan set according to the following rules:

Number detectors per phase as you approach the intersection and from right to left with Number 1 usually a detector back from the stop line and Number 2 to the left. At the stop line, Number 3 would be in the right lane with Number 4 to the left as you proceed to the intersection. These numbers should be proceeded by a D and the controller phase number (an example D8-1, D8-2, etc.). Also, if there is more than one detector in the left lane, Number 1 would be the first detector as you approach the intersection and Number 2 the second.

For controller functions, detectors will have a single unique number from 1 to 32. Therefore, the detector will have two labels; one for the plan sheet (i.e. D1-1) and one for the controller functions (i.e. Detector #1).

Refer to the **Exhibit 3-14**. At this intersection there are 8 phases. Each detector is labeled with the plan sheet label and local detector (LD) number. For instance, the northernmost detector is for phase 4 SBT. On the plan set, this is indicated as D4-1. For the LD Phase Assignment this is Detector #13.

Exhibit 3-14 Detector Labeling and Phase Assignment Diagram



Loop Detector Chart		
Designation	No. of Loops	Location
D1-1, D5-1	1	40'
D1-2, D5-2	1	10'
D2-1, D2-2	1	400'
D3-1, D7-1	2	20' & 50'
D3-2, D7-2	2	5' & 35'
D4-1, D8-1	1	300'
D6-1, D6-2	1	400'
D4-2, D8-2	1	5'
D4-3, D8-3	2	5' & 20'

Assigning TS2 Type 1 Detector Numbers

As noted above, the signal operator will label each detector with a unique number from 1 to 32. This is done by filling out the TS2 Type 1 Detector Phase Assignment list found at the following link:

www.dot.state.mn.us/trafficeng/signals/signalworksheets.html

The detector layout shown in the section above is used as an example to fill out the TS2 Type 1 Detector Phase Assignment in **Exhibit 3-16**.

In this example, detector D4-1 and D8-1 are set at 300' and D4-3 and D8-3 are at 20' back from the stop bar (per Figure 2 of the Signal Design Manual). At 45 mph, a vehicle takes 4.23 seconds to travel 280' (the distance between the detectors). However, it is not desirable to have detector D4-3 and D8-3 extend the phase 4.23 seconds. So, the vehicle extension can be set to 1.0 seconds. Then, detector D4-1 and D8-1 can have a detector extend of 3.23 seconds. This will allow the phase to extend the full 4.23 seconds between detectors but only 1.0 second after leaving phase D4-3 and D8-3.

Note that the Detector Phase Assignment Chart may be necessary for multiple times of days. That is, it is possible to have different Vehicle Detector Plans on a time of day basis. For instance, during one time period, the detector could operate with a delay time, but may have no delay time at different times of day.

Exhibit 3-15 Sample Vehicle Detector Settings (Econolite Aries)

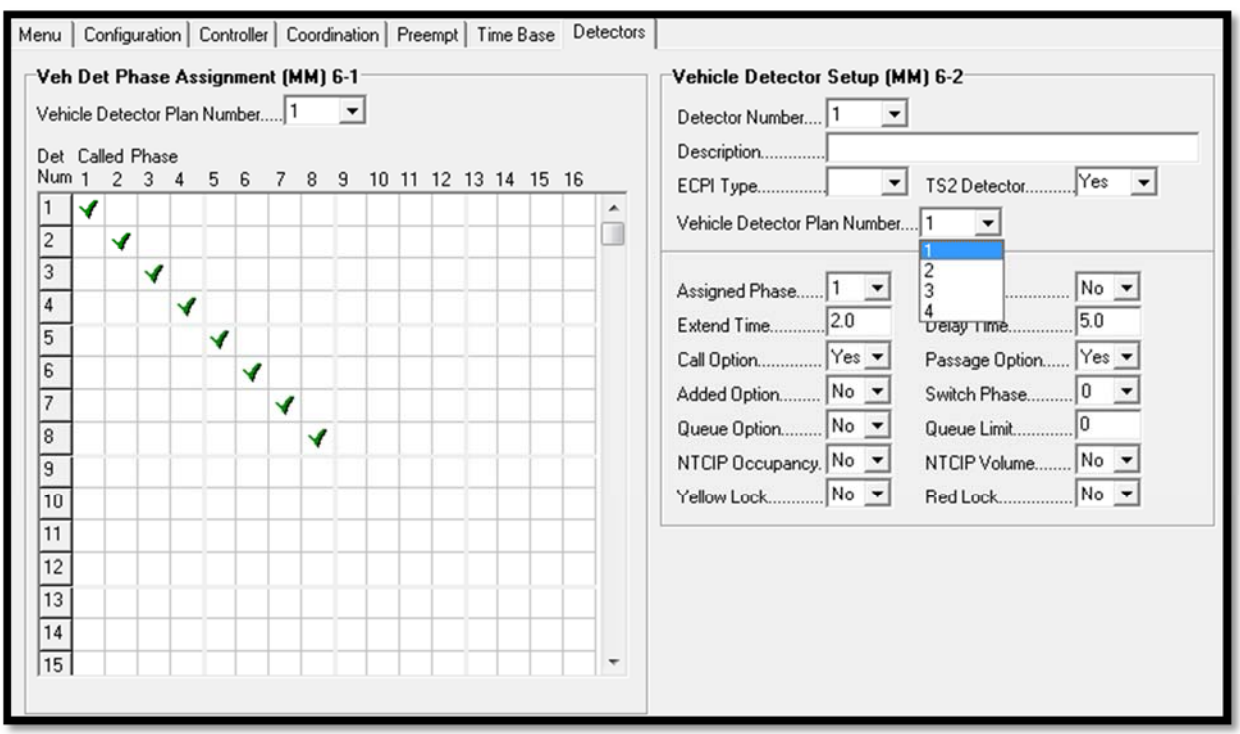


Exhibit 3-16 TS2 Type 1 Detector Phase Assignment Chart

TE# System I.D.# Date:

TS2 Type 1 Detector Phase Assignment

Intersection: TH 1 and Main St.

Rack 1 BIU Address 9

Zone	Local Detector	Detector #	*Type*	Phase 1	2	3	4	5	6	7	8	9	10	11	12	Extend	Delay
SA1	D1-1	1	0	x												0	0
	D1-2	2	0	x												0	0
	D5-1	3	0					x								0	0
	D5-2	4	0					x								0	0
SA2	D2-1	5	0		x											0	0
	D2-2	6	0		x											0	0
	D6-1	7	0						x							0	0
	D6-2	8	0						x							0	0
SA3	D3-1	9	0			x					x					0	0
	D3-2	10	0			x					x					0	0
	D7-1	11	0				x			x						0	0
	D7-2	12	0				x			x						0	15
SA4	D4-1	13	0				x									3.23	0
	D4-2	14	1				x									0	15
	D4-3	15	0				x									0	0
	D8-1	16	0								x					3.23	0

Rack 2 BIU Address 10

	Local Detector	Detector #	*Type*	Phase 1	2	3	4	5	6	7	8	9	10	11	12	Extend	Delay
SA1	D8-2	17	1								x					0	15
	D8-3	18	0								x					0	0
		19															
		20															
SA2		21															
		22															
		23															
		24															
SA3		25															
		26															
		27															
		28															
SA4		29															
		30															
		31															
		32															

***Types**
0 = Normal
1 = extend/delay
S = system

Note: Each rack is wired to support 4 additional channels of EVP or Pedestrian detection not shown above.

Detector assingments should be done in the following order:
1. All main line left turns
2. All main line thru lanes
3. All cross street left turns
4. All cross street thru lanes
5. All other detection (Overlaps, System Detectors)

3/20/2007

Common Detector Functions

Below is a list of the common by detector functions that can be used.

1. CALL & EXTEND — Upon actuation the detector immediately places a call on its associated phases at all times. The detector shall also immediately cause the controller to extend the green time for the actuating vehicle only during the green interval of that phase. The controller phase and the individual detector may be in Lock or Non-Lock mode.
2. DELAY CALL - IMMEDIATE EXTEND — When actuated during the yellow and red interval of its associated phase, the detector delays its output call for a pre-determined length of time during the extended presence actuation. After the time delay expires, the call remains active at the controller unit as long as the detector stays actuated. The detector shall also immediately cause the controller unit to extend the green time for the actuating vehicle only during the green interval of that phase. The controller phase and the individual detector may be in Lock or Non-Lock mode.
3. EXTEND ONLY — The detector immediately registers actuation at the Controller unit only during the green interval for that phase thus extending the green time before the actuating vehicles. The controller phase and the individual detector may be in Lock or Non-Lock mode.
4. SYSTEM — Any type of vehicle detector used to obtain representative traffic flow information.
5. CALL ONLY — Upon actuation the detector immediately places a call on its associated phase only during the red interval of that phase. This call remains active as long as the detector is actuated. The controller phase or individual detector may be in Lock or Non-Lock mode.
6. QUEUING — The detection of vehicles on one or more intersection approaches solely for the purpose of modifying the sequence and/or length of a phase.
7. CALL ONLY DENSITY — Upon actuation the detector immediately places a call on its associated phase only during the red interval of that phase. This call is inactivated when the controller unit outputs a check. This allows the use of density functions on this phase but necessitates the use of detector memory (lock) on the controller unit.
8. DELAY CALL DENSITY ONLY — When actuated during the red interval of its associated phase, the detector delays its output call for a pre-determined length of time during the extended actuation. This call is inactivated when the controller unit outputs a check and the time delay unit is not reset until after that phase has been served. This allows the use of density functions on this phase but necessitates the use of detector memory (lock).
9. CARRY-OVER CALL & EXTEND — Upon actuation the detector immediately places a call on its associated phase at all times and continues to output the call for a pre-determined length of time. The detector shall also immediately cause the controller unit to extend the green time for the actuating vehicle during the green interval of that phase and shall continue its output for a pre-determined length of time following an actuation. The controller unit may be in Lock or Non-Lock mode.

10. DELAY CALL ONLY — When actuated during the red interval of its associated phase, the detector delays its output call for a pre-determined length of time during the extended presence actuation. After the time delay expires, the call remains active at the controller unit as long as the detector remains actuated. The controller phase or individual detector may be in Lock or Non-Lock mode.
11. STOP BAR — Calls are accepted when the phase is not green and are held during green until the detector is empty, the detector is then disconnected. Additional Stop Bar functions are available where a timer can allow additional time before disconnect.

Summary of By Phase and By Detector Functions

As detailed throughout this manual, the signal operation has a variety of functions that can be applied by phase and/or by detector. The functions give the operator flexibility in controller the variable green time (the time between the minimum green and the maximum green).

The table below is a summary of some of the common functions available by phase and/or by detector. The list is not all inclusive of the functions available for each controller manufacturer.

Exhibit 3-17 Common Functions By Phase or By Detector

Function	By Phase	By Detector	Definition
Minimum Green	**X**		Refer to page 3-12 and page 4-17
Passage, Vehicle Extension, Gap	**X**	**X**	Refer to page 3-12 and page 4-18
Maximum Green	**X**		Refer to page 3-12 and page 4-20
Volume Density Control (gap reduction, added initial, computed initial)	**X**		Refer to page 3-14 and page 4-17
Recall	**X**		Refer to page 3-13
Lock Call	**X**	**X**	Refer to page 3-15 and below
Delay Call		**X**	Refer to page 3-36
Stop Bar		**X**	Refer to page 3-36

Detector Modes

Detectors can be operated in a pulse or presence mode. In pulse Mode the detector produces a short output pulse when detection occurs. In presence Mode the detector output continues if any vehicle (first or last remaining) remains in the zone of detection.

Detectors can also be operate with a lock or non-lock feature. The lock feature means that a vehicle call is held by the controller (even after the vehicle has left the detection area) until the call has been satisfied. This type of detection memory is usually associated with point detection such as one 6' X 6' (1.8 m X 1.8 m)

loop or a magnetometer. It has the advantage of minimizing detection costs, but is incapable of screening out false calls.

In the non-lock mode of memory, a waiting call is dropped by the controller as soon as the vehicle leaves the detection area. Non-lock detection memory is associated with large areas of detection at the stop line. This type of operation can reduce delay by screening out false calls, but has greater installation costs due to the large areas of detection needed.

Detection Design

The information following this page is a handout taken from the Minnesota Department of Transportation Signal Design Manual. The most current version of the Signal Design Manual can be found at:

www.dot.state.mn.us/trafficeng/publ/index.html

It is recommended that you review all original reference material.

HANDOUT

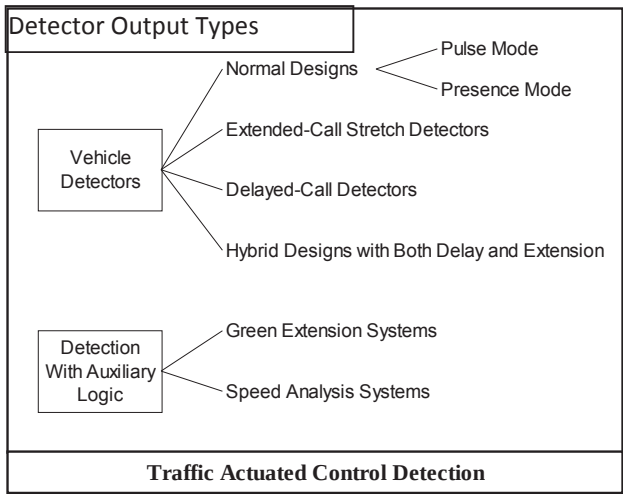
4.4 VEHICLE DETECTION TYPES

The different types of vehicle detectors available include but are not limited to the following types:

- **Magnetic/Magnetometer** detects moving ferrous metal objects – pulse.
- **Photo electric/Infrared** detects a break in a beam of light – presence or pulse.
- **Radar/Microwave** detects moving objects by sending and receiving electronic pulses – pulse.
- **Ultrasonic** detects sound with a microphone – presence or pulse.
- **Inductive loop** detects a change in resonant frequency by the introduction of a ferrous metal in the magnetic field of the detection zone.
- **Video** detects a change in a video pixel range – presence or pulse.
- **Microloop** detects a change by moving ferrous metal in the earth's magnetic field – pulse.

4.5 TYPES OF VEHICLE DETECTION

The Figure at the right is a classification of types of detection for traffic actuated controllers.



Some detectors record vehicles whether stopped or in motion. Others require that the vehicle be moving at a speed of at least 2 or 3 mph.

1. Normal loop or magnetic detectors will operate in either the pulse mode or presence mode. The magnetic detector produces a short output pulse when detection occurs, no matter how long the vehicle remains in the detection area. The normal loop is intended to produce a detector output for as long as a vehicle is in the field of detection.
2. An extended-call detector has a "carryover output", meaning that it holds or stretches the call of a vehicle for a period of seconds that has been set on an adjustable timer incorporated into the controller or detector.
3. A delayed-call detector does not issue an output until the detection zone has been occupied for a period of seconds that has been set on an adjustable timer incorporated into the controller or detector. Hybrid detector designs incorporating both delay and extension are now relatively common.

Current industry standard traffic signal controllers extend the capabilities of the normal detector/controller hardware. This controller functionality employs auxiliary timers and monitors circuits. This functionality allows the enabling and disabling of selected detectors, control of the yield of green, and the activation of "Hold-in Phase" circuits in order to supplement controller timing.

1. Examples of controller functionality are; locking memory, non-lock, delay call, extend (stretch) call, and stop bar.
2. Another type of detection is the "speed analysis system". This system is a hardware assembly composed of two loop detectors and auxiliary logic. The two loops are installed in the same lane a

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precise distance apart. A vehicle passing over the loops produces two actuations. The time interval between the first and the second actuation is measured to determine vehicle speed.

4.5.1 Inductive Loop Detectors

The most common type of vehicle detection device in use today is the inductive loop. This is a loop of wire imbedded in the pavement (saw cut in existing concrete or Rigid PVC loop in new concrete) carrying a small electrical current. When a large mass of ferrous metal passes over the loop, the magnetic field is disturbed and generates, or induces, a change in resonant frequency in the wire. This change in frequency is then recognized by the detector amplifier and signals the controller that a vehicle is present.

4.5.2 Microwave Radar Detectors

Development of microwave radar during World War II enabled this technology to be applied to detection of vehicular traffic. The principles of operation involve microwave energy being beamed on an area of roadway from an overhead antenna, and the vehicle's effect on the energy detected. The antennas capture a portion of the transmitted energy reflected toward them by objects in the field of view. By direct comparison of transmitted energy with reflected energy from a moving vehicle, a Doppler beat note can be detected which in turn can be used to operate an output device. Use of continuous wave (CW) transmission and reliance on the use of a Doppler signal from the return wave eliminates the need for any gating or distance measurement, and, thereby, provides a simple detector responsive to vehicles **moving** through the field. By appropriate processing of information in the received energy, direct measurements of vehicle presence, occupancy, and speed can be obtained.

4.5.3 Video image processing

Vehicle detection by video cameras is one of the most promising new technologies for non-intrusive large-scale data collection and implementation of advanced traffic control and management schemes. This concept provides real-time vehicle detection and traffic parameter extraction from images generated by video cameras. Major worldwide efforts have been directed at development of a practical device for image processing. Under FHWA sponsorship, a wide-area, multi-spot Video Imaging Detector System (VIDS) was developed at the University of Minnesota and is commercially available.

A video image processing system typically consists of the following components:

- Image hardware - The imaging sensor is an electronic camera (conventional TV camera or an infrared camera) that overlooks a section of the roadway and provides the desired image information.
- Processor - A processor determines vehicle presence or passage from images received by the camera. It also provides other traffic parameters preferably in real-time.
- Software - Advanced tracking system software performs operations, detector programming, viewing of vehicle detections, and roadway surveillance.

Image processing detection systems can detect traffic in many locations (i.e., multiple spots) within the camera's field of view. These locations can be specified by the user in minutes using interactive graphics, and can be changed as often as desired. This flexible detection is achieved by placing detection lines along or across roadway lanes on a TV monitor displaying the traffic scene (not physically placed in the pavement). Each time a vehicle image crosses these lines, a detection signal (presence or passage) is generated. The result is similar to that produced by loop detectors.

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VIDS are advantageous in traffic detection since:

- They are mounted above the road rather than in the road, providing multi-lane coverage along with installation and servicing advantages of traffic flow maintenance and personnel safety during detector repair.
- Placement of vehicle detection zones on the road is not limited to a particular detection configuration. The configuration can be controlled and adjusted manually (by an operator with a computer terminal) or dynamically (by software) at any time, as a function of traffic flow.
- The shape of the detection zone can be programmed for specific applications, such as freeway incident detection, detection of queue lengths (that cannot easily or economically be derived by conventional devices) and detection of turning patterns on city arterials.

Video detection design is not covered in this class. Work with the vendor on the proper design of video detection.

4.6 MNDOT VEHICLE DETECTION PRACTICES

4.6.1 Definition of Terms

CALL	A registration of a demand for the right-of-way by traffic at a controller unit.
CHECK	An outgoing circuit of the controller unit that indicates the existence of an unanswered call.
DETECTOR	A device for indicating the presence or passage of vehicles.
ACTUATION	The operative response of any type of detector.
DETECTOR	The retention of an actuation for the future utilization by the controller unit.
NON-LOCKING	A mode of actuated-controller-unit operation which does not require detector memory.

Depending on the controller type, the function may or may not be used.

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4.6.2 Loop Detector Placement Design

1. **Guaranteed Green.** By detector design and functioning, all vehicles except right turn on red (RTOR) vehicles will be guaranteed service of a green light within a cycle. A positive call will be placed to the controller in advance of the stop line to give service to 100% of the vehicles that need a green. If right turns can be segregated from thru and right turn movements, a lock operation can be used with special detector functioning to guarantee a green. If right turn segregation is not possible, and a non-lock operation must be used, ample front detection must be provided to assure all vehicles are given a green at variable stopping locations.
2. **Safety.** Consideration must be given to winter as well as summer conditions. Advanced detection (passage) must be provided at all posted speeds at or above 35 mph (55 km/hr). Advanced detection will greatly reduce : 1. Vehicles skidding into the intersection, 2. rear end accidents, 3. right angle accidents, 4. delay. Detection that doesn't guarantee required greens will cause drivers to take chances and have accidents.
3. **Failsafe**. Alternatives must be provided for when a primary detector fails so that non mainline phases do not have to be placed on recall. Typically an advanced (passage) detector will become the primary detector when a stop bar detector fails and the phase is placed in the lock mode. In other situations detector delay times can be removed. With left turn detectors, faulty detectors can be unspliced from multiple detectors. Fixed time recalls should be avoided.
4. **Maintenance**. Detectors should be located in a good roadbed, if the surface is in a very poor condition it should be replaced. Multiple "Home Runs" (loop lead ins) should be avoided when crossing multiple lanes, as it will cause pavement failure and possibly crosstalk. Conduits should be installed to eliminate long home runs when possible. Consideration should be given to installing non-intrusive detectors to reduce maintenance complexity."
5. **Operation.** Detectors should provide operation that is logical to the driving public. Drivers should not feel that they were "cut off ", overly delayed, or have to make quick decisions. The average driver in the United States spends six months of his or her life waiting at traffic signals.

4.6.3 Loop Detector Cable Lead-ins

A typical MnDOT signal controller cabinet detector rack will have space for 32 detectors (6 - four channel detector cards), two EVP cards (2- two channel) and a one 4 channel or 2 two channel Pedestrian Isolator cards. The new cabinets will support 8 - 4 channel or 16 - 2 channel detectors. Adding EVP does not reduce the number of loop detector channels.

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4.7 VEHICLE DETECTOR EXHIBITS

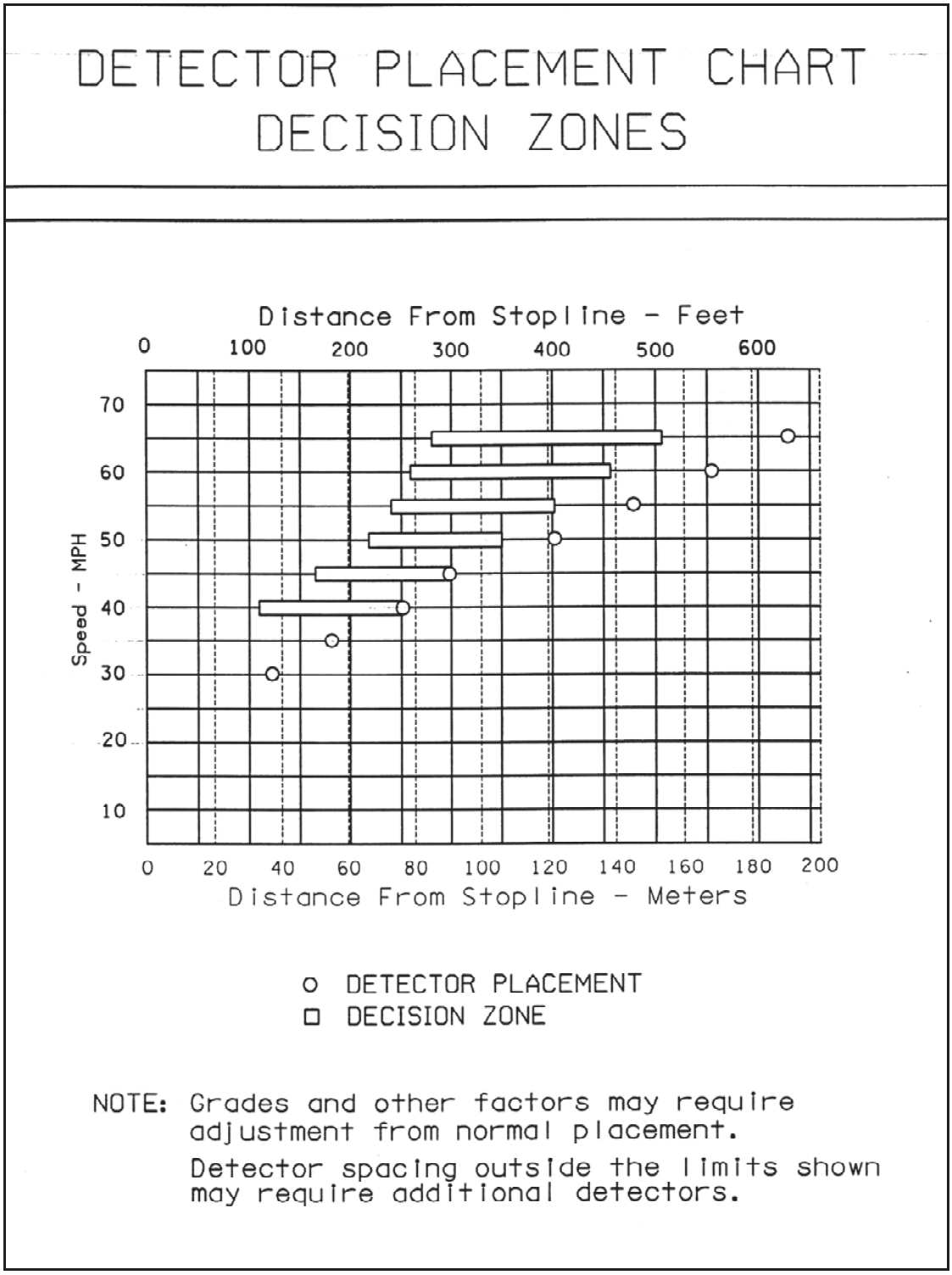
The exhibits on the following pages (**4-26** to **4-35**) are typical detector layouts for a variety of situations. They are arranged as shown below.

Exhibit	Page	Comments
Exhibit 4-1 Detector Placement Chart – Decision Zones	4-26	Shows the placement of a detector considering vehicle decision zones.
Exhibit 4-2 Major Approach	4-27	These are developed based on the decision zones. Chart includes an optional mid-point detector.
Exhibit 4-3 Minor Approach with Right Turn Lane (RTOR Allowed)	4-28	Typical minor street arrangement with permissive only left turn movements.
Exhibit 4-4 Minor Approach Protected / Permissive Left - 1 Through Lane	4-29	Minor street arrangement with a protected / permissive operation (or FYA) and 1 through lane.
Exhibit 4-5 Minor Approach Protected / Permissive Left - 2 Through Lanes	4-30	Minor street arrangement with a protected / permissive operation (or FYA) and 2 through lanes.
Exhibit 4-6 Protected Permissive and FYA Left Turn	4-31	Exclusive left turn lane, 4-loop configuration used for a protected / permissive left (includes a FYA).
Exhibit 4-7 Protected Left Turn - Lock Operation	4-32	Exclusive left turn lane with raised median, 2-loop configuration used for a protected left turn using lock mode.
Exhibit 4-8 Protected Left Turn - Non Lock Operation	4-33	Exclusive left turn lane with raised or painted median, 4-loop configuration
Exhibit 4-9 Minor Approach	4-34	Minor approach with no exclusive turn lanes. This configuration would not be typically used for a new intersection.
Exhibit 4-10 Leading Protected / Permissive Left Turn from a Through Lane	4-35	Approach with no exclusive turn lanes and a protected / permissive left turn operation. This configuration would not be typically used for a new intersection.

These charts are generally intended for new signals designs and <u>may not be feasible for a rebuild/modification</u>. If the design is a rebuild or modification, these charts can act as guidance, but engineering judgment should be applied.

HANDOUT

Exhibit 4-1 Detector Placement Chart – Decision Zones

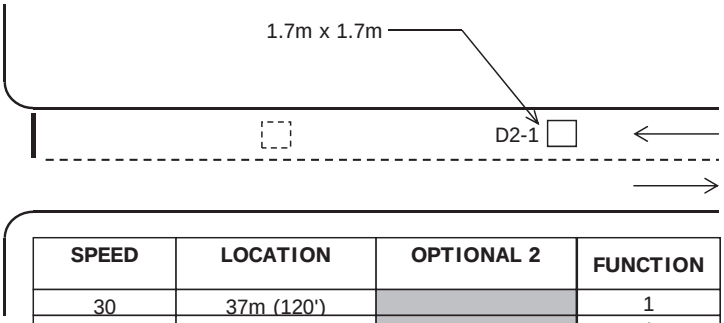


HANDOUT

Exhibit 4-2 Major Approach

LOOP DETECTOR PLACEMENT

MAJOR APPROACH



SPEED	LOCATION	OPTIONAL 2	FUNCTION
30	37m (120')		1
35	55m (180')		1
40	76m (250')		1
45	92m (300')		1
50	122m (400')		1
55	145m (475')	75m (240')	1
60 *	168m (550')	84m (275')	1
65 *	191m (625')	96m (315')	1

LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

* ONLY APPLY TO DIVIDED 4-LANE ROADWAY

LOOP DETECTOR FUNCTIONS

1 = CALL AND EXTEND

NOTES:

1) THE LOOP DETECTOR FUNCTION IS CALL AND EXTEND.

2) ONE LOOP FOR EACH APPROACH LANE. AN EFFORT TO EXTEND TURN LANES BEYOND DETECTOR LOCATIONS WILL ENHANCE OPERATIONS EFFICIENCY.

3) IF USING MID-POINT DETECTORS, ENSURE THE LEFT AND RIGHT TURN POCKETS BEGIN BEFORE THE MID-POINT DETECTOR.

4) CONTROLLER PHASE SHALL BE ON VEHICLE RECALL.

5) CONTROLLER PHASE DENSITY FUNCTION (ADDED INITIAL GREEN) SHALL BE USED.

6) OPTIONAL 2 POINT SPACING MAY BE USED FOR 2 LANE ROADWAY WITH SPEED LIMITS OF 45 MPH OR GREATER. SEE CHART FOR LOCATION OF ADDITIONAL LOOP DETECTOR.

7) OPTIONAL STOP LINE DETECTION MAY BE CONSIDERED FOR SHORTENED MINIMUM GREEN TIME.

FIGURE 1

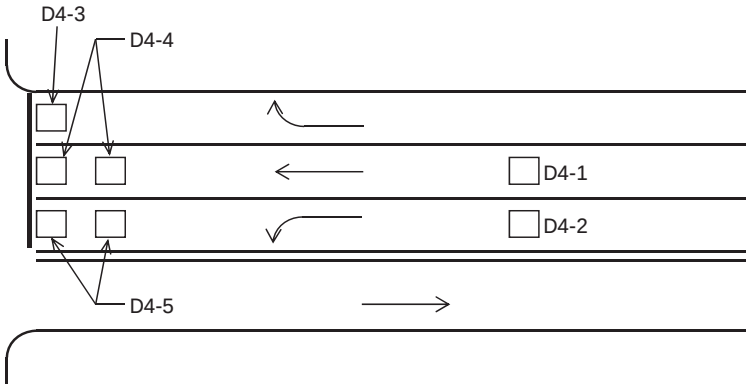
HANDOUT

Exhibit 4-3 Minor Approach with Right Turn Lane (RTOR Allowed)

LOOP DETECTOR PLACEMENT

MINOR APPROACH

WITH RIGHT TURN LANE (RTOR ALLOWED)



LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

SPEED	LOCATION
30	37m (120')
35	55m (180')
40	76m (250')

LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND
7 = DELAY CALL - IMMEDIATE EXTEND

NUMBER	FUNCTIO	SIZE
D4-1	1	1.7 x 1.7m (6' X 6')
D4-2	1	1.7 x 1.7m (6' X 6')
D4-3	7	1.7 x 1.7m (6' X 6')
D4-4	1	2 - 1.7 x 1.7m (6' X 6')
D4-5	1	2 - 1.7 x 1.7m (6' X 6')

NOTES:

1) CONTROLLER PHASE CAN OPERATE IN NON-LOCKING MODE.

2) DETECTOR D4-3 COULD BE LARGER (6' X 10', 6' X 12', ETC.) TO ACCOUNT FOR LARGER RIGHT RADIUS.

FIGURE 2

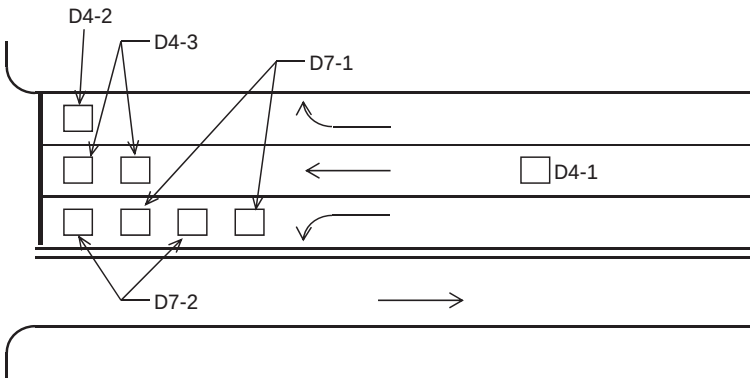
HANDOUT

Exhibit 4-4 Minor Approach Protected / Permissive Left - 1 Through Lane and Right Turn Lane (RTOR Allowed)

LOOP DETECTOR PLACEMENT

MINOR APPROACH PROTECTED/PERMISSIVE LEFT

1 THROUGH LANE & RIGHT TURN LANE (RTOR ALLOWED)



LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND
7 = DELAY CALL - IMMEDIATE EXTEND

SPEED	D4-1
30	37m (120')
35	55m (180')
40	76m (250')

NUMBER	FUNCTIO	SIZE	LOCATION
D4-1	1	1.7 x 1.7m (6' X 6')	SEE LEFT
D4-2	7	1.7 x 1.7m (6' X 6')	1.5m (5')
D4-3	1	2 - 1.7 x 1.7m (6' X 6')	1.5 & 6m (5' & 20')
D7-1	1	2 - 1.7 x 1.7m (6' X 6')	6m (20') & 15m (50')
D7-2	1	2 - 1.7 x 1.7m (6' X 6')	1.5m (5') & 11m (35')

NOTES:

1) CONTROLLER PHASE CAN OPERATE IN NON-LOCKING MODE.

2) THE LEFT TURN LOOPS WILL CROSS SWITCH WITH THE THROUGH PHASE.

3) SEE FIGURE 5 FOR ADDITIONAL NOTES ON PROTECTED/PERMISSIVE OPERATION.

4) DETECTOR D4-2 COULD BE LARGER (6' X 10', 6' X 12', ETC.) TO ACCOUNT FOR LARGER RIGHT RADIUS.

FIGURE 3

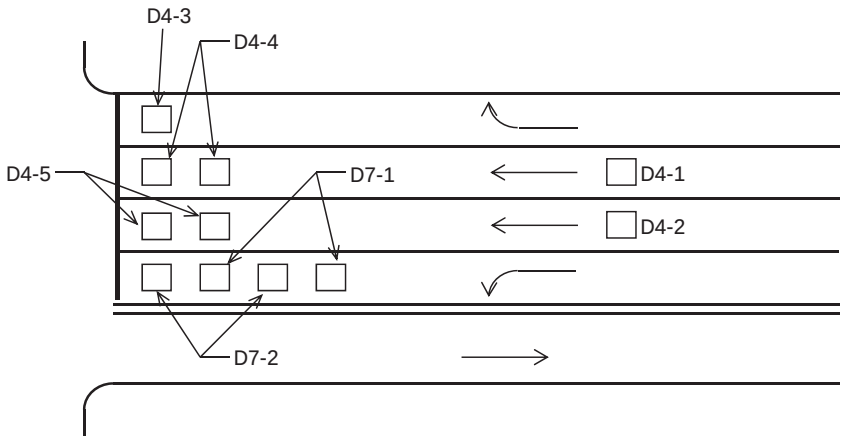
HANDOUT

Exhibit 4-5 Minor Approach Protected / Permissive Left - 2 Through Lanes and Right Turn Lane (RTOR Allowed)

LOOP DETECTOR PLACEMENT

MINOR APPROACH PROTECTED/PERMISSIVE LEFT

2 THROUGH LANES & RIGHT TURN LANE (RTOR ALLOWED)



LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND
7 = DELAY CALL - IMMEDIATE EXTEND

SPEED	D4-1
30	37m (120')
35	55m (180')
40	76m (250')

NUMBER	FUNCTIO	SIZE	LOCATION
D4-1	1	1.7 x 1.7m (6' X 6')	SEE LEFT
D4-2	1	1.7 x 1.7m (6' X 6')	SEE LEFT
D4-3	7	1.7 x 1.7m (6' X 6')	1.5m (5')
D4-4	1	2 - 1.7 x 1.7m (6' X 6')	1.5 & 6m (5' & 20')
D4-5	1	2 - 1.7 x 1.7m (6' X 6')	1.5 & 6m (5' & 20')
D7-1	1	2 - 1.7 x 1.7m (6' X 6')	6m (20') & 15m (50')
D7-2	1	2 - 1.7 x 1.7m (6' X 6')	1.5m (5') & 11m (35')

NOTES:

1) CONTROLLER PHASE CAN OPERATE IN NON-LOCKING MODE.

2) THE LEFT TURN LOOPS WILL CROSS SWITCH WITH THE THROUGH PHASE.

3) SEE FIGURE 5 FOR ADDITIONAL NOTES ON PROTECTED/PERMISSIVE OPERATION.

4) DETECTOR D4-3 COULD BE LARGER (6' X 10', 6' X 12', ETC.) TO ACCOUNT FOR LARGER RIGHT RADIUS.

FIGURE 4

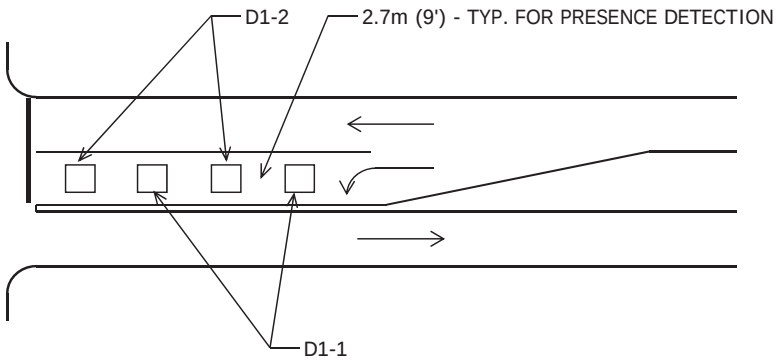
HANDOUT

Exhibit 4-6 Protected Permissive and FYA Left Turn – Separate Left Turn Lane

LOOP DETECTOR PLACEMENT

PROTECTED/PERMISSIVE AND FLASHING YELLOW LEFT TURN

SEPARATE LEFT TURN LANE



LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND

NUMBER	FUNCTION	SIZE	LOCATION
D1-1	1	2 - 1.7 x 1.7m (6' X 6')	6m (20') & 15m (50')
D1-2	1	2 - 1.7 x 1.7m (6' X 6')	1.5m (5') & 11m (35')

LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

NOTES:

1) CONTROLLER PHASE AND DETECTOR FUNCTION SHALL BE NON-LOCK MEMORY WITH NO RECALL.
2) USE BACK UP PROTECTION TO PREVENT LEFT TURN TRAP IF THERE ARE OPPOSING LEFT TURNS.
3) DESIGN SPEED IS 25 MPH.
4) EACH NUMBERED LOOP DETECTOR SHALL HAVE A SEPARATE LEAD-IN CABLE AND SEPARATE AMPLIFIER.
5) IF USING NMC LOOPS, A SINGLE LARGER LOOP CAN REPLACE THE DUALS.
6) DETECTOR CROSS SWITCHING MAY BE USED.
7) USE THIS FIGURE IF INSTALLING A FLASHING YELLOW ARROW (FYA).

FIGURE 5

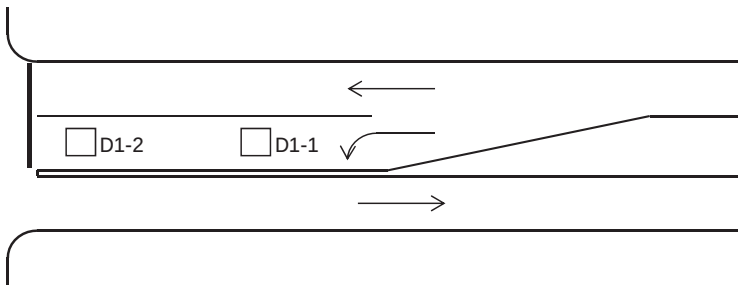
HANDOUT

Exhibit 4-7 Protected Left Turn - Lock Operation – Raised Median

LOOP DETECTOR PLACEMENT

PROTECTED LEFT TURN

LOCK OPERATION - RAISED MEDIAN



LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

FRONT LOOP	BACK LOOP
3m (10')	12m (40')

LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND

NUMBER	FUNCTIO	SIZE
D1-1	1	1.7 x 1.7m (6' X 6')
D1-2	1	1.7 x 1.7m (6' X 6')

NOTES:

1) NO DENSITY FUNCTIONS ARE USED.

2) THE DESIGN SPEED IS 25 MPH.

3) EACH NUMBERED LOOP DETECTOR SHALL HAVE SEPARATE LEAD-IN CABLE AND SEPARATE AMPLIFIER.

4) LOCKING MEMORY SHALL BE USED BY PHASE OR DETECTION FUNCTION. NO CONTROLLER RECALL.

5) THIS CONFIGURATION MAY BE CONSIDERED FOR A FYA OPERATION RETRO-FIT PROJECT.

FIGURE 6

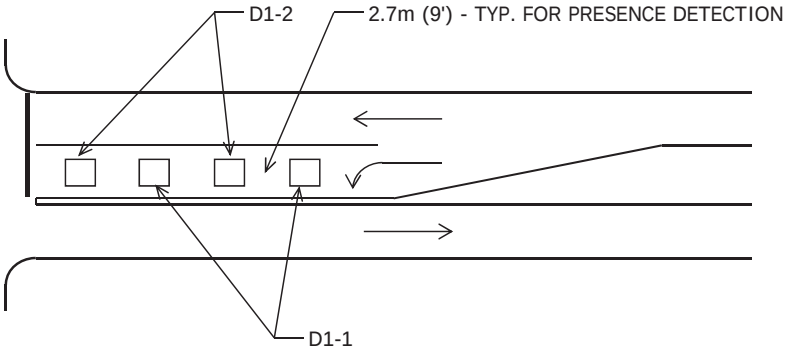
HANDOUT

Exhibit 4-8 Protected Left Turn - Non Lock Operation – Painted and Non-Raised Median

LOOP DETECTOR PLACEMENT

PROTECTED LEFT TURN

NON LOCK OPERATION - PAINTED & NON-RAISED MEDIAN



LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND

NUMBER	FUNCTIO	SIZE	LOCATION
D1-1	1	2 - 1.7 x 1.7m (6' X 6')	6m (20') & 15m (50')
D1-2	1	2 - 1.7 x 1.7m (6' X 6')	1.5m (5') & 11m (35')

LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

NOTES:

1) **USE IN LOCATIONS WHERE VEHICLES PUT IN FALSE CALLS DUE TO CROSSING OVER DOUBLE YELLOW LINES.**

2) NO DENSITY FUNCTIONS ARE USED.

3) THE DESIGN SPEED IS 25 MPH.

4) EACH NUMBERED LOOP DETECTOR SHALL HAVE SEPARATE LEAD-IN CABLE AND SEPARATE AMPLIFIER.

5) IF LOOPS ARE USED FOR COUNTING, ONE LOOP ON D1-1, THREE LOOPS ON D1-2

6) IF USING NMC, MAY COMBINE DUALS AS LARGER LOOPS.

7) THE CONTROLLER PHASE AND DETECTION FUNCTIONS SHALL BE ON NON-LOCK WITH NO RECALL.

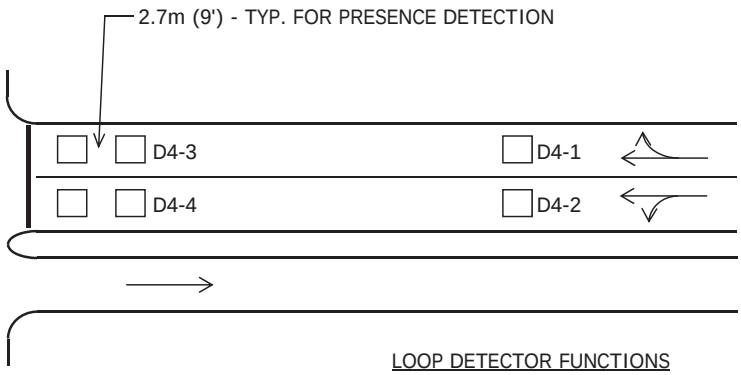
FIGURE 7

HANDOUT

Exhibit 4-9 Minor Approach

LOOP DETECTOR PLACEMENT

MINOR APPROACH



LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND
3 = EXTEND ONLY
7 = DELAY CALL - IMMEDIATE EXTEND
8 = STOP BAR
9 = STOP BAR WITH DELAY CALL

LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

SPEED	FRONT LOOP	BACK LOOP
30	1.5 & 6m (5' & 20')	37m (120')
35	1.5 & 6m (5' & 20')	55m (180')
40	1.5 & 6m (5' & 20')	76m (250')
45	1.5 & 6m (5' & 20')	92m (300')
50	1.5 & 6m (5' & 20')	122m (400')
55	1.5 & 6m (5' & 20')	145m (475')

NUMBER	FUNCTION	SIZE
D4-1	3	1.7 x 1.7m (6' X 6')
D4-2	1	1.7 x 1.7m (6' X 6')
D4-3	7 OR 9	2 - 1.7 x 1.7m (6' X 6')
D4-4	1 OR 8	2 - 1.7 x 1.7m (6' X 6')

NOTES:

1) THE ADDED INITIAL DENSITY FUNCTION IS NOT NECESSARY BECAUSE OF FRONT DETECTORS. THE GAP REDUCTION DENSITY FUNCTION MAY BE CONSIDERED.

2) CONTROLLER PHASE AND DETECTOR FUNCTION SHALL BE NON-LOCK MEMORY WITH NO

3) PROVIDE GOOD COVERAGE FOR FRONT DETECTION FOR VARIABLE STOPPING LOCATIONS. USE ANY COMBINATION OF 1.7m x 1.7m (6' x 6') OR 1.7m x 3m (6' x 10') LOOP DETECTORS.

4) IF USING NMC LOOP, MAY COMBINE DUAL LOOPS.

5) ADVANCED DETECTION IS OPTIONAL.

6) USED WITH PRESENCE DETECTION.

FIGURE 8

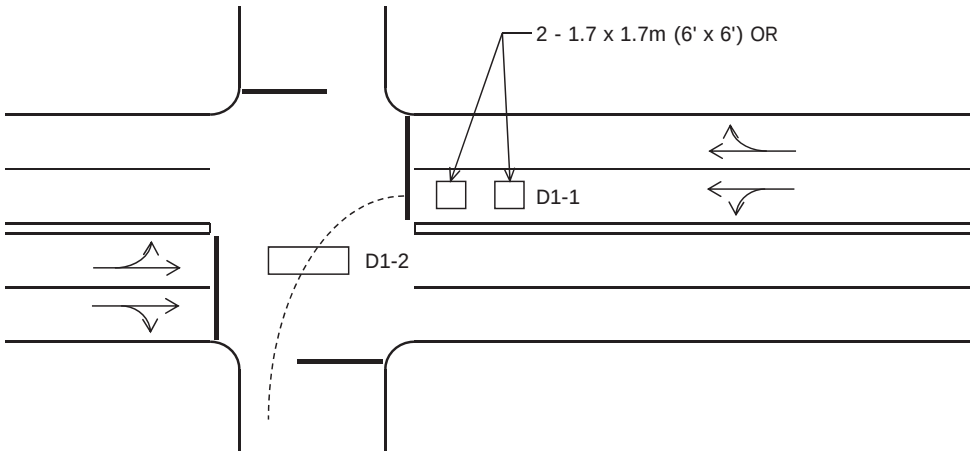
HANDOUT

Exhibit 4-10 Leading Protected / Permissive Left Turn from a Through Lane

LOOP DETECTOR PLACEMENT

LEADING PROTECTED/PERMISSIVE LEFT TURN

FROM A THROUGH LANE



LOOP DETECTOR LOCATION:
D1-1 IS LOCATED 1.5m (5') FROM STOP BAR.

D1-2 IS LOCATED OPPOSING THROUGH LANE, CENTERED IN THE TURNING RADIUS OF LEFT TURNING VEHICLES.

LOOP DETECTOR FUNCTIONS
3 = EXTEND ONLY
5 = DELAY CALL ONLY

NUMBER	FUNCTIO	SIZE
D1-1	5	2 - 1.7 x 1.7m (6' X 6')
D1-2	3	1.7 x 6m (6' X 20')

NOTES:

1) LOOP D1-1 SHALL HAVE A 1 - 2 SECOND DELAY, 2 SECOND STRETCH (EXT.), AND IS ONLY ACTIVE DURING PHASE RED.

2) LOOP D1-2 WILL ONLY EXTEND IT'S OWN PHASE (GREEN ARROW).

3) USE BACK UP PROTECTION TO PREVENT LEFT TURN TRAP IF THERE ARE OPPOSING LEFT TURNS.

4) CONTROLLER PHASE DENSITY FUNCTIONS SHALL NOT BE USED.

5) CONTROLLER PHASE AND DETECTOR FUNCTION SHALL BE ON NON-LOCK MEMORY.

6) THE DESIGN SPEED IS 20 MPH.

7) IF NO OPPOSING LEFT TURN, NOTE 3 IS NOT NECESSARY.

FIGURE 9

3.10 Measures of Effectiveness

All traffic signal timing and analysis models produce at least some estimates of performance, or measures of effectiveness (MOEs). There are two general classes of MOEs: 1) estimates of performance measures that allow the analyst to evaluate the quality of the system, and 2) performance measures which in fact serve as the explicit objective function of the optimization. Only optimization models are concerned with the later type.

The exact way each of the models derive these estimates varies, so this discussion is general.

Degree of Saturation

Degree of Saturation is defined as:

$$X = vC / sg$$

where,

X = degree of saturation expressed as a decimal value or multiplied by 100 to form a percentage,

v = volume in vph,

C = cycle length in seconds,

s = saturation flow in vphg, and

g = effective green (split time - lost time).

You may notice that moving the cycle length to the denominator results in sg/C, which is the capacity, so the degree of saturation is also commonly called the volume-to-capacity (v/c) ratio.

If the program says you have a "X" that is approaching or exceeding saturation (100%) and you know this is not actually occurring, several things could be wrong. Any of the four input elements may have been mis-coded, so you will need to check and correct your input data. If the data checks out, your saturation flow rate is probably wrong. If you estimated it, you should now do a field study to pin it down more accurately. Another possibility is your lost time was too high--again do a study (see computer model calibration section).

On the other hand, if the approach really is saturated, for evaluation purposes you will have to do some extra analysis.

Another related ratio is the so-called "flow ratio (Y),"

$$Y= v / s$$

where all terms have been defined.

This is the proportion of time that must be available to satisfy the particular movement(s) represented by the v and s. Decisions on critical movements are generally made based on the Y values.

You may also identify all of the critical, conflicting movements and sum their Y values. If the result exceeds 1.0 (or even a little less, because some part of each cycle is lost time as discussed earlier), no amount of signal timing can solve the saturation problem at this intersection. Only more concrete or asphalt, or less traffic, will avoid saturation.

Example – Degree of Saturation Calculation*:* Assume the following:

Northbound through volume = 600 vph

Cycle length = 60 seconds

Green Split = 35 seconds

Lost time = 5 second

Adjusted saturation flow = 1700 vphg

Then,

$X = vC / sg = (600\ vph)(60\ sec) / (1700\ vphg)(35\text{-}5\ sec)$

$X = 0.71$ or 71%

Delay

All of the standard computer models have this MOE in one form or another; indeed it is often part of the optimization objective. You will need to review the respective user documentation to see how delay is calculated.

All optimization models effectively deal in the equivalent of a single cycle. They recognize that, for particular conditions, traffic characteristics tend to repeat similarly for successive cycles. This is especially true in a coordinated system, which depends on the uniformity of repeated cycles. In most models even today, delay is estimated using a method introduced by Webster years ago, or variations of this model.

In the 2000 Highway Capacity Manual (HCM), the average control delay per vehicle is estimated for each lane group and averaged for approaches and the intersection as a whole. The average control delay per vehicle for a given lane group is given by:

$d = d_1PF + d_2 + d_3$

$d_1 = 0.50C\ [1\text{-}g/C]^2/\{1\text{-}[Min(1,X)](g/C)\}$

$d_2 = 900T\ \{(X\text{-}1) + [(X\text{-}1)^2 + (8kIX/cT)]^{0.5}\}$

$d_3 = [1800Q_b(1+u)t]/cT$, or zero

Where:

d = average control delay, sec/veh;

d_1 = uniform control delay, sec/veh;

d_2 = incremental delay, sec/veh;

d_3 = residual delay, sec/veh;

PF = uniform delay progression adjustment factor;

X = v/c ratio for lane group;

C = cycle length, sec;

c = capacity of lane group, vph;

g = effective green time for lane group, sec;

m = incremental delay calibration term representing the effect of arrival type and degree of platooning;

Q_b = initial unmet demand at the start of period T, veh;

T = duration of analysis period, hr;

I = upstream filtering/metering adjustment factor;

k = incremental delay factor that is dependent on controller settings;

t = duration of unmet demand in T, hr; and

u = delay parameter

d_1 gives an estimate of delay assuming perfectly uniform arrivals and stable flow. It is based on the first term of Webster's delay formulation and is widely accepted as an accurate depiction of delay for the idealized case of uniform arrivals. Note that values of X beyond 1.0 are not used in the computation of d_1.

d_2 estimates the incremental delay due to nonuniform arrivals and temporary cycle failures (random delay) as well as that caused by sustained periods of oversaturation (oversaturation delay). It is sensitive to the degree of saturation of the lane group (X), the duration of the analysis period of interest (T), the capacity of the lane group (c), and the type of signal control as reflected by the control parameter (k). The formula assumes that there is no unmet demand causing residual queues at the start of the analysis period (T). Finally, the incremental delay term is valid for all values of X, including highly oversaturated lane groups.

d_3 is applied when a residual demand from a previous time period causes a residual queue to occur at the start of the analysis period (T), additional delay is experienced by the vehicles arriving in the period, since the residual queues must first clear the intersection. If this is not the case, a d_3 value of zero is used. This procedure is also extended to analyze delay over multiple time periods, each having a duration (T) in which a residual demand may be carried from one time period to the next.

It must be emphasized that every model uses a different method to calculate delay (and other MOEs for that matter). You cannot compare the measures from one model to another. Also, microscopic simulation models usually include mid-block speed perturbations as delay, while macroscopic models ignore this. Naturally, you should expect to see similar trends among models, but the absolute values cannot be compare across models, thus only compare MOEs developed by one model for different scenarios.

Level of Service

Level of service for signalized intersections is defined in terms of delay, which is a measure of driver discomfort, frustration, fuel consumption, and lost travel time. The delay experienced by a motorist is made up of a number of factors that relate to control, geometrics, traffic, and incidents. Total delay is the difference between the travel time actually experienced and the reference travel time that would result during ideal conditions: in the absence of traffic control, in the absence of geometric delay, in the absence of any incidents, and when there are no other vehicles on the road. Control delay includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. In contrast, in previous versions of the HCM (1994 and earlier), delay included only stopped delay. Control delay may also be referred to as signal delay.

Specifically, LOS criteria for traffic signals are stated in terms of the average control delay per vehicle, typically for a 15-min analysis period. The criteria are given in the table below. Delay is a complex measure and is dependent on a number of variables, including the quality of progression, the cycle length, the green ratio, and the v/c ratio for the lane group in question.

Exhibit 3-18 Level of Service Criteria for Signalized Intersections (2000 HCM)

Control Delay Per Vehicle (Sec)	Level Of Service
≤ 10.0	A
> 10.0 and ≤ 20.0	B
> 20.0 and ≤ 35.0	C
> 35.0 and ≤ 55.0	D
> 55.0 and ≤ 80.0	E
> 80.0	F

HCM 2010 Notes

The Transportation Research Board (TRB) recently updated the methods in the Highway Capacity Manual. This is the 2010 Edition and is the fifth major revision to the HCM. This edition of the 2010 HCM incorporates years of new research and integrates a multimodal approach. The 2010 HCM is divided into four (4) volumes. The first three volumes are printed chapters and the fourth volume is electronic only.

Of relevance to this Traffic Signal Timing and Coordination Manual are the new 2010 HCM Chapters 18 on Signalized intersections and Chapter 31 as a supplement to Chapter 18. These chapters present a new delay method and structure changes reflecting modern actuated control.

The updated LOS table for the HCM 2010 methods is presented below.

Exhibit 3-19 Level of Service Criteria for Signalized Intersections (2010 HCM)

	Level Of Service by v/c Ratio[1]	
Control Delay Per Vehicle (Sec)	v/c ≤ 1.0	v/c > 1.0
≤ 10.0	A	F
> 10.0 and ≤ 20.0	B	F
> 20.0 and ≤ 35.0	C	F
> 35.0 and ≤ 55.0	D	F
> 55.0 and ≤ 80.0	E	F
> 80.0	F	F

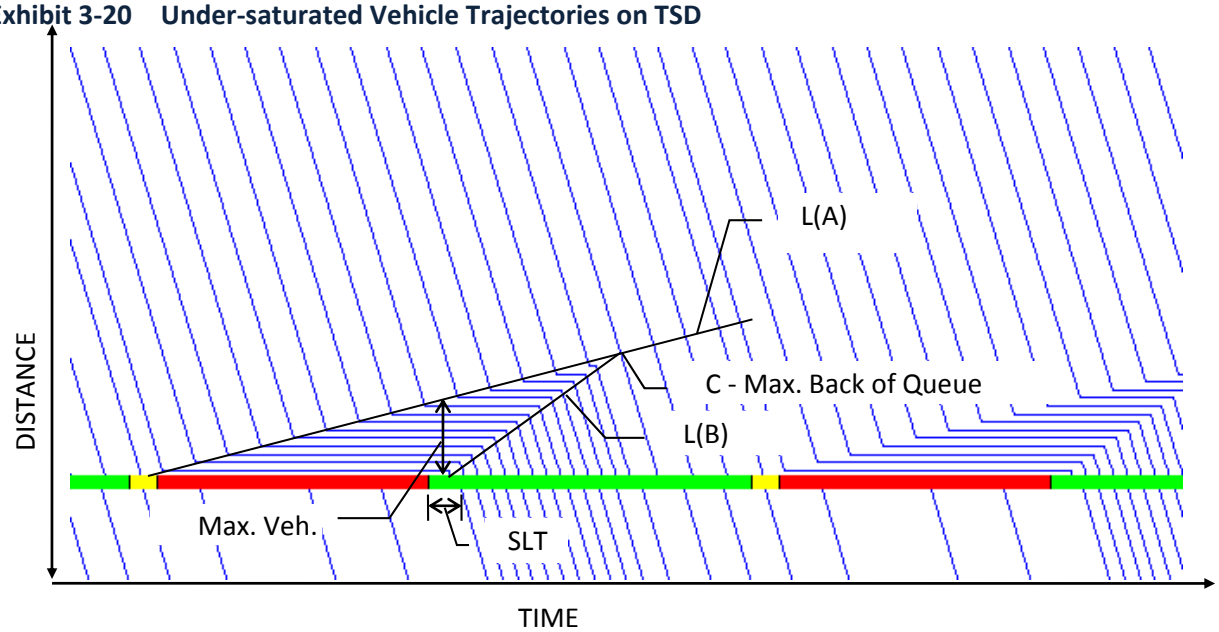
[1]Note: For approach-based and intersection wide assessments, LOS is defined solely by control delay.

Additional details can be found in the 2010 Highway Capacity Manual.

Stops

Stops have a much more significant effect on traffic performance than might intuitively be expected. This measure is calculated by the various models in several ways, so it is not appropriate to present a particular method here. Suffice it to say that stops are significantly different under normal operations, vs. saturated conditions. Consider the figure that follows, which is a time-space diagram of a single approach showing individual vehicle trajectories.

Exhibit 3-20 Under-saturated Vehicle Trajectories on TSD



Under saturated Conditions

The vehicle arriving during the red and, indeed, early in the green, clearly must stop. This is depicted by the flat slope of their trace lines. Those arriving when the queue is nearly dissipated, however, do not come to a complete stop, thus their traces never fall completely flat, but rather lie at a slope representing a reduced speed.

This figure is also significant from an academic perspective. The trace of points (in mathematical terms, the locus) in time and space at which arriving, queuing vehicles stop (points "A") is shown by the line "L(A) " in the figure. The slope of this line is the arrival rate in vehicles per unit time. If this figure was indeed accurately scaled, the arrival rate could actually be quantified. Likewise, the trace (locus) of points of vehicles departing the queue ("B") has a slope that represents the departure rate. Since this is the maximum departure rate, it is also the saturation flow rate, as defined earlier.

Also, in mathematical sense, the area inside the triangle formed by the horizontal axis and L(A)-L(B) constitutes the uniform delay as defined by Webster. This points out an intuitively obvious fact: where there are stops, there is delay. Some models, however, actually look at this from the opposite perspective: if a vehicle is delayed, it must have been stopped (e.g., TRANSYT-7F).

A typical deterministic model for deriving the number of stops under pre-timed control is expressed as follows:

$$P_s = \frac{rs}{C(s-v)}$$

where P_s = percentage of vehicles stopped, which is multiplied by the volume to obtain the number of vehicles stopped;

r = length of effective red for the movement, sec;

s = saturation flow rate, vphg;

C = cycle length, sec; and

v = volume of the movement, vph.

Example Percentage of Vehicles Stopped

Assume the following:

Northbound through volume = 600 vph

Cycle length = 60 seconds

Green Split = 35 seconds

Lost time = 5 second

Adjusted saturation flow = 1700 vphg

Then,

g = Split - Lost time = (G + Y) - L

r = C - g = C – (Split - Lost Time) = 60 - 35 + 5 = 30 seconds

P_s = rs/[C(s-v)] = (30 sec)(1700 vphg) / [(60 sec)(1700 - 600 vph)] = 0.77 or 77%

Other deterministic models use different models for this purpose. PASSER II's model, for example, adjusts for the platooning of vehicles. See their user guides for more details.

TRANSYT-7F, being a simulation model, expressly considers the full stop vs. the partial stop. This is explained further in the TRANSYT-7F Users Guide.

Saturated Conditions

The second condition is when the approach is saturated. In reality, vehicles arriving at the back of the queue will normally not reach the intersection in one cycle. They advance their position in the queue, but stop again. NO macroscopic model deals with multiple stops and the other effects of saturation (other than a loose estimate of the added delay). Microscopic models (such as SimTraffic and CORSIM) deal more properly with this, and this is one of their main advantages.

Queuing

It is not surprising that stops and queuing are even more closely related than stops and delay. A vehicle stopped, or nearly stopped, adds to the queue length. Conceptually, the queue is the vertical "distance" between L(A) and L(B) in the previous figure. The maximum length of the queue actually occurs at the beginning of effective green. At that point the departure rate "L(B)" is greater than the arrival rate "L(A)," so the vertical "distance" between the dashed lines diminishes thereafter. Notice that the convergence of the arrival/departure traces at point C represents the point in time <u>and space</u> at which the queue itself has ended, or dissipated. Now notice <u>where</u> this is--at the maximum distance <u>upstream</u> of the stop line.

This is referred to as the "maximum back of queue (MBQ)" and is reported in Synchro and TRANSYT. All other macroscopic models (e.g., SOAP, PASSER II, etc.) report the maximum queue length, if they report queuing at all. The MBQ is clearly more important, because it shows how far upstream the queue will extend, potentially spilling over into intersections, or backing out of turn bays and blocking the through lane.

Unfortunately, TRANSYT-7F does not deal with the <u>effect</u> of spillover, as explained in its Users Guide. As of release 6, however, TRANSYT-7F does consider the excess maximum back of queue it its optimization process. It is important to note that if spillover actually does occur, the signal timing models do not give realistic results. The results of the simulations will not be reliable as long as spillover is a distinct possibility. In the case of TRANSYT-7F, you can, however, approximate the effect of the spillover. The special technique is described in its Users Guide.

Synchro 6 and later includes a method for queue delay. Refer to the Synchro section for further details.

In contrast to the macroscopic models, the microscopic simulation models explicitly deal with queuing.

Fuel Consumption

Fuel consumption models developed for signal timing methods generally meet the following criteria:

- ✓ The model predicts fuel consumption based on the MOEs produced by the program.
- ✓ The model accounts for the fact that the optimization can alter the numerical relationship between delay and stops.
- ✓ The model is simple and easy for researchers to calibrate.

The MOEs used in typical fuel consumption models are the following:

- ✓ Total travel in vehicle-miles (vehicle-kilometers)/hour.
- ✓ Total delay in vehicle-hours/hour,
- ✓ Total stops in vehicles/hour, and
- ✓ Cruise speed on the approach, or link.

Most macroscopic fuel models have been empirically calibrated by field studies where data were analyzed by stepwise multiple regression, resulting in the following model form:

$F_i = K_{i1}\ TT_i + K_{i2}\ D_i\ K_{i3}\ S_i$

where,

F_i = fuel consumed on link I, in gallons (liters) per hour;

TT_i = total travel in veh-mi (veh-km) per hour;

D_i = total delay in veh-hr per hour;

S_i = total stops in vph; and

K_{ij} = model coefficients which are functions of cruise speed (V_i) on each link I:

$K_{ij} = A_{j1} + A_{j2}\ V_i + A_{j3}\ Vi^2$

where A_{jk} = regression coefficients.

This is the "classic" model form used by TRANSYT-7F. The coefficients in the TRANSYT-7F fuel model have been calibrated to generalize the model to be representative of the distribution of sales by vehicle size; although, these are not always very current.

The TRANSYT-7F fuel model is also used in Synchro and PASSER II. It is important that users of the TRANSYT-7F fuel model understand its limitations, which are obviously common to other versions of similar models, albeit for somewhat different reasons:

- ✓ The model parameters were determined from studies conducted with only one test vehicle, but the model coefficients were adjusted to be representative of an "average" vehicle in the fleet. The last update to this, however, was 1983.
- ✓ No explicit consideration was given to factors such as traffic congestion, vehicle type mix (i.e., trucks and diesel engines) or geometric and environmental factors such as road gradient, curvature, surface quality, temperature and other factors.

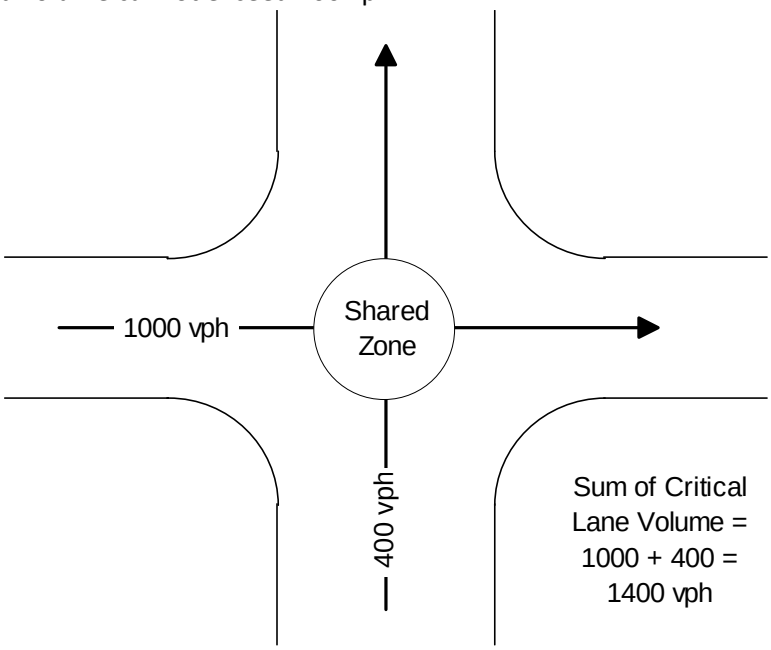
These limitations suggest that the conclusions about the <u>absolute</u> values of the fuel estimates be used with appropriate caution. On the other hand, the <u>relative</u> estimates from the existing signal timing plan to the optimized timing plan should reasonably reflect the trend that can actually be expected to occur, except when saturated conditions exist.

3.11 Critical Lane Analysis

Introduction

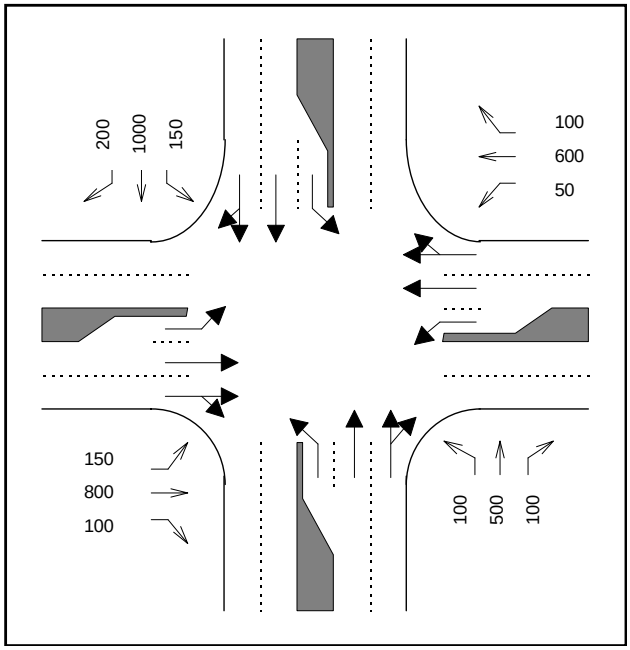
Critical lane analysis is a simple planning and operational tool intended in sizing the overall geometrics of the intersection or in identifying the general capacity sufficiency of an intersection. The basic procedure is as follows:

- ✓ The capacity of a point where intersecting lanes of traffic must cross is equal to 1,400 vehicles per hour (vph). In the example shown below, if 1,000 vph is the demand on the eastbound approach, then the northbound volume cannot exceed 400 vph.

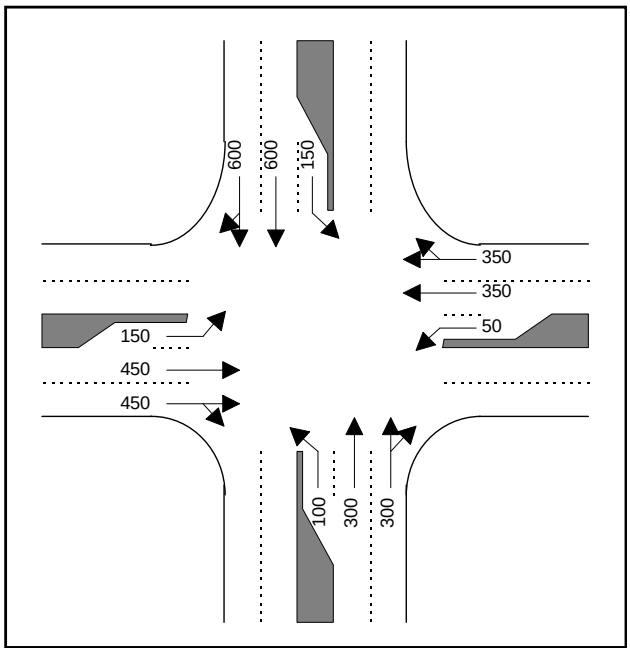


- ✓ This procedure does not consider the detail of lane width, parking conditions, or other features, nor does it consider the number of trucks and buses in the traffic stream.
- ✓ Critical Movement Analysis identifies critical movements by individual lanes. Thus hourly approach volumes must be assigned by lane.
- ✓ Where exclusive turning lanes are present, all turns are assigned to the appropriate turning lane.
- ✓ For shared and/or through lanes when permissive left turns are not present, volume is distributed equally among the available lanes.

Example: Given the following intersection geometrics and hourly traffic movements:



The Lane Volumes are assigned as follows:



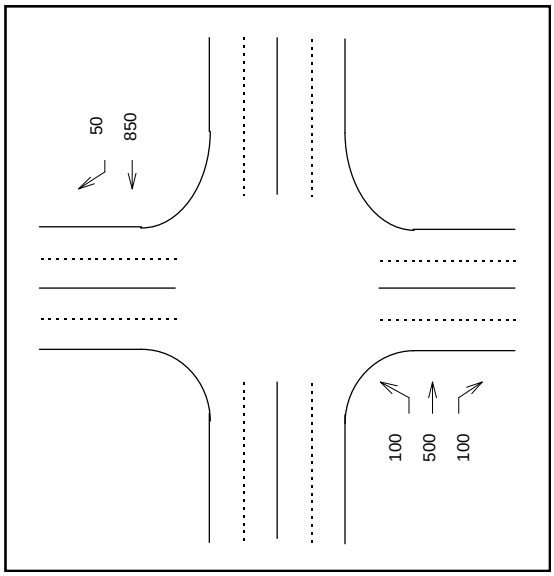
- ✓ When permissive left turns are included in shared lanes, vehicles are assigned to available through and shared lanes in equal numbers of through vehicle equivalents. All right turning traffic and through vehicles have a through vehicle equivalent (TVE) of 1.00, while permissive left turns have the following values:

Exhibit 3-21 Critical Lane TVE

Opposing Through and Right-Turn Volume, V_o (vph)	Through Vehicle Equivalent (TVE)
0-100	1.0
100-199	1.1
200-599	2.0
500-799	3.0
800-999	4.0
≥ 1000	5.0

This distribution is subject to the requirement that all left turns be assigned to the left-most shared lane.

***Example*:** Given the figure below, determine the distribution of traffic on the northbound approach of the following intersection:



First, convert the 100 left turners to through vehicle equivalents:

Opposing volume = 900 (850 + 50)

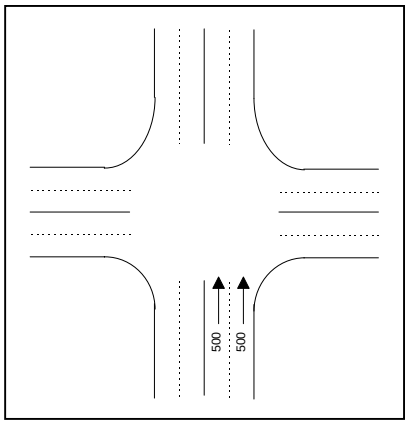
Each left turner = 4.0 TVE or

100 x 4.0 = 400 TVE

Next, load up lanes equally with remaining volume plus through vehicle equivalents:

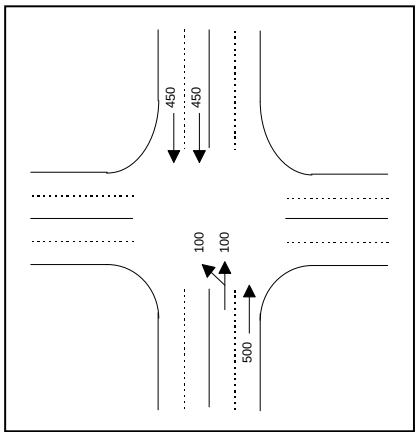
500 through + 100 right + 400 TVE = 1000

1000/2 = 500



Of the 500 vehicles in the inside lane, 400 are through vehicle equivalents that represent left turners. Therefore, the remaining 500 - 400 = 100 vehicles in the inside lane are actually through vehicles.

Now, distribute traffic in actual traffic movements:



Capacity Analysis

The capacity analysis is carried out by identifying a critical lane volume for each signal phase, and summing these critical lane volumes.

- ✓ The sum of the critical lane volumes can be compared with the values in the following table to obtain a general evaluation of probable traffic conditions at the intersection.

Exhibit 3-22 Critical Lane Volume Relationship to Probable Capacity

Sum of Critical Lane Volumes, vph	Relationship to Probable Capacity
0 - 1200	Under Capacity
1201 - 1400	Near Capacity
≥ 1400	Over Capacity

- Capacity will vary considerably with the cycle length, number of phases, grades, lane widths, presence of heavy vehicles, and numerous other factors. The values in this table represent a range of normally-occurring situations, including:
    a. Cycle lengths from 30 to 120 seconds,
    b. Percent heavy vehicles from 0% to 10%,

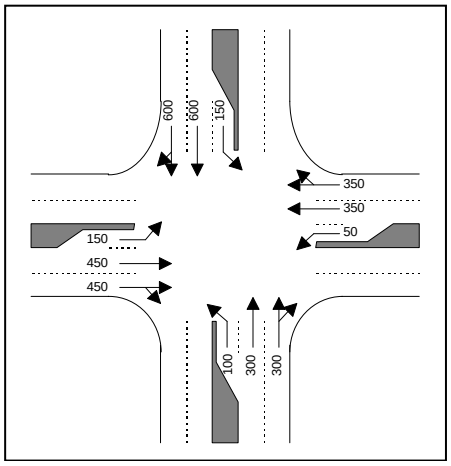
c. Level terrain, and,

d. Standard lane widths from 10 ft to 12 ft.

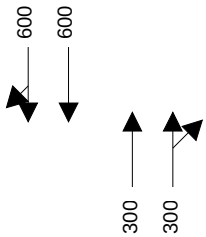
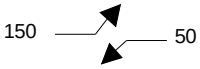
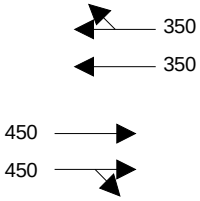
- For this range of conditions, critical volumes of less than 1,200 vph will virtually always be below the capacity of the intersection, while values greater than 1,400 vph will be more than the capacity of the intersection in most cases. For critical volumes between 1,200 and 1,400 vph, judgment is difficult, as the specific characteristics notes above will be important in determining whether or not capacity is exceeded. For such cases, the only possible general evaluation is that the volume is "near" capacity of the intersection, and could be less than or more than capacity depending upon prevailing conditions.
- However, it may be noted that in general, a traffic operational scheme that produces a lower sum of critical lane volumes will result in better intersection operations than an alternative that produces a higher sum.

✓ If left turns are served only on protected left turn phases, then the critical lane volume for each phase is simply identified as the highest lane volume that receives a green indication on that phase.

***Example**:* Assume that a 4-phase signal operation with protected lefts is used for the intersection shown below (from previous examples):



Critical lane volumes are identified and summarized as follows:

PHASE	MOVEMENTS	CRITICAL LANE VOLUME
1		150
2		600
3		150
4		450
Sum Of Critical Volumes = 1350		

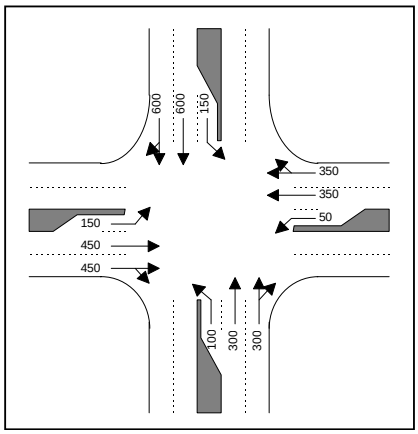
- ✓ If left turns are allowed as a permissive movement during the same phase as opposing through traffic, then we have to account for the conflicts between these movements. The "critical lane volume" for a signal phase becomes the highest total of the <u>through</u> single lane volume plus its opposing <u>left</u>.
  - For a north-south street, critical conflicts are the NB left turn movement with the SB through movement and the SB left turn movement with the NB through movement. The critical lane volume for the north-south street is the largest sum among:
    - The NB left turn volume plus the maximum single lane volume for the SB through plus right turn movement, or
    - The SB left turn volume plus the maximum single lane volume for the NB through plus right turn movement.

    Similarly, the critical lane volume for the east-west street is the greatest among:
    - The EB left turn volume plus the maximum single lane volume for the WB through plus right turn movement, or

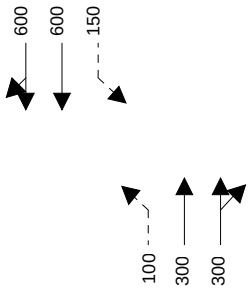
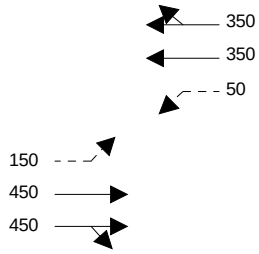
- The WB left turn volume plus the maximum single lane volume for the EB through plus right turn movement.

The total critical lane volume for the intersection is the sum of the critical lane volumes for the north-south and east-west street.

Example: Once again, use the following intersection. This time, however, assume two-phase signal operation with permissive lefts.



Critical lane volumes are identified and summarized as follows:

PHASE	MOVEMENTS	CRITICAL LANE VOLUME
1		600 + 100 = <u>700</u> This is greater than 150 + 300 = 450
2		350 + 150 = <u>500</u> This is equal to 450 + 50 = <u>500</u>
Sum Of Critical Volumes = 1200		

✓ This critical lane volume procedure gives us an evaluation of the overall operational level of the intersection, but does not evaluate the need for special phasing (particularly for left turning traffic).

- In the previous example perhaps the 100 northbound left turners that are opposed by the southbound 1200 through and right turning vehicles may need a separate phase.

  The maximum left turn volume that can be accommodated as a permissive movement (i.e., without a left turn phase) can be computed as the maximum of:

$C_{LT} = (1400 - V_o)\ (g/C)_{PLT}$

or:

C_{LT} = 2 vehicles per signal cycle

where:

C_{LT} = capacity of the left turn permissive phase, vph,

V_o = the opposing through plus right turn movement, vph, and

$(g/C)_{PLT}$ = the effective green ratio for the permissive left turn phase.

- The g/C ratio for each phase is normally assumed to be proportional to the highest approach lane volume for the phase when compared with approach lane volumes for the other phases. For simplicity, we generally do not include the opposing left turn volumes in calculating this proportion. For a two-phase signal, we can estimate g/C for phase 1 as:

$$(g/C)_1 = \frac{V_1}{V_1 + V_2}$$

For a multiphase signal, we can estimate g/C for phase 1 as:

$$(g/C)_1 = \frac{V_1}{V_1 + V_2 + V_3 + \ldots + V_N}$$

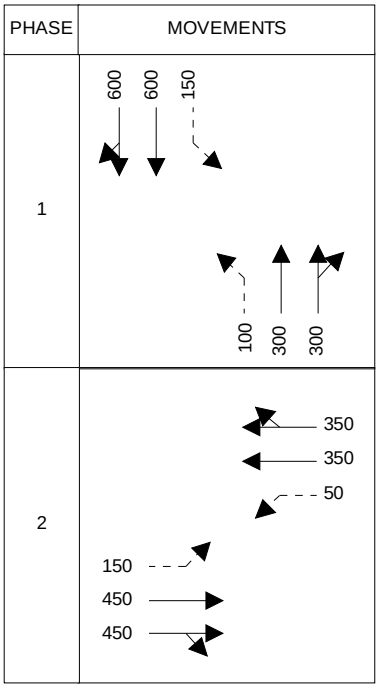
where:

$(g/C)_1$ = the effective green ratio for phase 1,

V_1 = the highest approach lane volume moving on phase 1

$V_2 + V_3 + \ldots + V_N$ = The highest approach lane volumes moving on each of the other phases.

***Example**:* Using the previous example, determine if potential left turn phases are required



For the NB left turns,

$C_{LT} = (1400 - V_o)\ (g/C)_{NB}$

where:

$V_o = 600 + 600 = 1200$

$(g/C)_{NS} = 600 / (600 + 450) = 0.57$

$C_{LT} = (1400 - 1200)\ (0.57) = 114 > 100$ NB left turners

In addition, as a minimum left turn capacity, we can count on an average of two left turns on the clearance period following each permissive phase, even when opposing traffic volumes are so heavy that no left turns can occur on the green indication. Therefore, minimum NB left turn capacity,

C_{LT} = (2 x 3600 sec/hr) / (cycle length in sec.)

If a 60 second cycle is used, C_{LT} = (2 x 3600) / 60 = 120 left turns.

Summary of Critical Lane Analysis

A summary of the critical lane method for evaluating the adequacy of a signalized intersection is as follows:

- ✓ Assign traffic volumes to lanes.
  1. Separate turn lanes accommodate their respective turning movements.
  2. Right turns are equivalent to through movements if a separate turn lane is not provided.
  3. If separate left turn lanes are not used, lane distribution is attained through the use of through vehicle equivalents.
  4. If there are single lane approaches, special adjustments must be made to account for the impeding effect of left turning vehicles.
- ✓ Check if two-phase signal operation is feasible or if a multi-phase operation is required to provide protected left turn movements.
- ✓ Identify critical movements for each signal phase.
- ✓ Evaluate level of intersection operation based on summation of critical movements.

4 LOCAL INTERSECTION TIMING

4.1 Timing Practices

Assuming that the traffic control signal has been designed and installed in accordance with good technical practices, proper timing is the final ingredient to create an efficiently operating traffic control signal. The objective of signal timing is to alternate the right of way between traffic streams so that average total delays to all vehicles and pedestrians, and that the possibility of crash-producing conflicts are minimized.

The purpose of this manual is to establish uniform guidelines for MnDOT personnel to time traffic control signals. It is intended to set forth accepted practices, procedures and guidelines. It should be noted that there are no legal requirements for the use of these practices, procedures and guidelines. The legal considerations are set forth in the state law and the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD).

It should also be noted that these guidelines, procedures and practices are general and should be used only as a general guide. Many other factors at each individual intersection must be considered and good engineering judgment must be utilized in applying these guidelines. Field observations and timing adjustments must be done to maximize the efficiency and safety of the traffic control signal operation. A series of timing adjustments may be necessary.

The timing values developed through these procedures may not in all cases be directly set on all traffic control signal controllers. Each manufacturer may have a different way of timing each timing function. Care must be taken in knowing the theory of operation of each traffic control signal controller and setting values in the traffic signal controller.

There are basically two types of traffic signal controllers; pre-timed (fixed timed) and traffic actuated (variably timed). The guidelines, procedures and practices apply more directly to traffic actuated controllers, because the majority of MnDOT's controllers are the traffic actuated type.

Traffic control signal controllers can be operated in a free (isolated) or a coordinated (system) mode of operation. This section of this guideline will address the free (isolated) mode of operation.

In timing a traffic signal, a good understanding of the meaning of the signal indications is necessary. The meaning of signal and pedestrian indications can be found in the MN MUTCD in Section 4D.

4.2 Full Traffic Actuated Timing Controls

The following are basic timing parameters that are necessary for a traffic signal controller to operate. These guidelines, procedures and practices are based on them. MnDOT uses microprocessor controllers manufactured to NEMA, TS2-type2 standards. There are other functions and parameters that need to be installed on each particular manufacturer controllers. Each manufacturer's traffic controller manual should be reviewed and understood before operating the controller in a field application. Any questions as to using these other functions or parameters should be directed to the Traffic Signal Engineer.

1. WALK - Establishes the length of the WALK interval.
2. PEDESTRIAN CLEARANCE (CHANGE) - Establishes the length of flashing DON'T WALK interval.
3. MINIMUM GREEN - Establishes the length of initial state of green interval.
4. ADDED INITIAL - Density feature. Establishes number of seconds by which each vehicle (actuation) builds added initial state of green during non-green time on phase.

5. PASSAGE TIME - Establishes the increment of right of way (green) time extension for each vehicle actuation during the green interval.
6. TIME BEFORE REDUCTION - Density feature. Establishes a preset time before allowed gap begins to reduce.
7. TIME TO REDUCE - Density feature. Establishes time in which the allowed gap is reduced from passage time to minimum gap, after the time before reduction has expired.
8. MINIMUM GAP - Density feature. Establishes minimum value to which allowed gap between actuations on phase with green can be reduced upon expiration of time to reduce.
9. MAXIMUM GREEN - Establishes the maximum limit to which the green interval can be extended on a phase in the present of a serviceable demand on a conflicting phase.
10. YELLOW - Establishes the length of yellow interval following the green interval.
11. RED - Establishes the length of red interval following the yellow interval.
12. MEMORY MODES - Establishes whether the controller will remember (lock) or drop (non-lock) vehicle actuation.
13. RECALL MODES - Establishes whether the controller automatically returns to and provides right-of-way (green) on the selected phase once each traffic signal cycle, without the need for vehicle demand for service. There is pedestrian, minimum vehicle and maximum vehicle recall modes.

4.3 Local Free By TOD

The above section lists some of the settings required for a local intersection controller. Some of these values can vary based on a time of day (TOD), day of week, week of year and special holiday program. Some of the parameters that can be changed include:

- ✓ Maximum time setting (Max I, Max II, Max III)
- ✓ Dynamic Max
- ✓ Phase omit
- ✓ Conditional service inhibit
- ✓ Flash
- ✓ Red Rest
- ✓ Alternate vehicle extension
- ✓ Alternate sequence
- ✓ Vehicle recall
- ✓ Vehicle max recall
- ✓ Pedestrian recall
- ✓ Additional features may exist based on the controller

Flashing Yellow Arrow operation (permitted, protected, or protected/permitted) can also be run on a TOD basis. For details, refer to page **4-26**.

The **Exhibit 4-1** illustrates that the local controller will use the clock and day information to choose the appropriate program and step.

Exhibit 4-1 Local Controller TOD Program Step

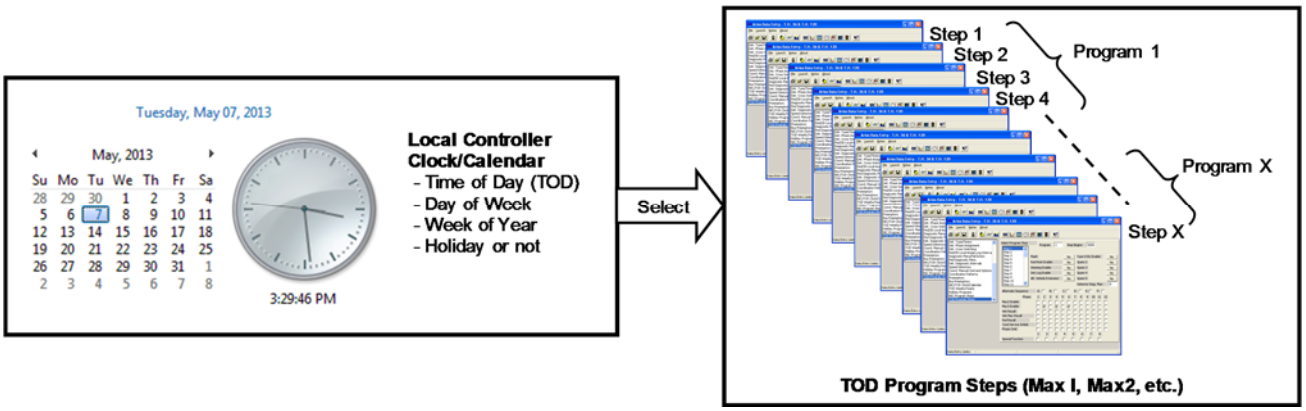


Exhibit 4-1 does not address intersections running in a coordinated system. The intent is for an intersection running in free mode operation. Coordinated systems will be discussed in Chapter 5.

4.4 Local Intersection Start-up Process

Start-up of a local intersection is the sequence of operation following a dark or flash condition.

Typical MnDOT operation once the intersection is powered up;

- ✓ Flash All Red for 10 seconds
- ✓ All Red for 6 seconds
- ✓ then begin service on Phases 2 & 6 green
- ✓ Normal sequence follows.

Below is information from the MN MUTCD, section 4D.31.

4D.31 Flashing Operation - Transition Out of Flashing Mode

STANDARD:

All changes from flashing mode to steady (stop-and-go) mode shall be made under one of the following procedures:

A. Yellow-red flashing mode: Changes from flashing mode to steady (stop-and-go) mode shall be made at the beginning of the major-street green interval (when a green signal indication is displayed to through traffic in both directions on the major street), or if there is no common major-street green interval, at the beginning of the green interval for the major traffic movement on the major street.

B. Red-red flashing mode: Changes from flashing mode to steady (stop-and-go) mode shall be made by changing the flashing red indications to steady red indications followed by appropriate green indications to begin the steady mode cycle. These green indications shall be the beginning of the major-street green interval (when a green signal indication is displayed to through traffic in both directions on the major street) or if there is no common major-street green interval, at the beginning of the green interval for the major traffic movement on the major street.

GUIDANCE:

The steady red clearance interval provided during the change from red-red flashing mode to steady (stop and go) mode should have a duration of 6 seconds.

When changing from the yellow-red flashing mode to steady (stop-and-go) mode, if there is no common major-street green interval, the provision of a steady red clearance interval for the other approaches before changing from a flashing yellow or a flashing red signal indication to a green signal indication on the major approach should be considered.

STANDARD:

During programmed changes out of flashing mode, no flashing yellow signal indication shall be terminated and immediately followed by a steady red or flashing red signal indication without first displaying the steady yellow signal indication.

OPTION:

Because special mid-block signals that rest in flashing circular yellow in the position normally occupied by the green signal indication do not have a green signal indication in the signal face, these signals may go directly from flashing circular yellow (in the position normally occupied by the green signal indication) to steady yellow without going first to a green signal indication.

4.5 Pedestrian Timing Requirements

This section will cover the WALK and PEDESTRIAN CLEARANCE (*flashing* DON'T WALK) parameters.

The MN MUTCD requires that pedestrians should be assured of sufficient time to cross the roadway at a signalized intersection. This must be shown with the vehicle and/or pedestrian indications. In the absence of pedestrian indications, the minimum green + yellow + all red time must be equal to pedestrian timing (walk + pedestrian clearance).

The MN MUTCD meaning of pedestrian signal indications are summarized as follows:

- ✓ WALK indication, means that pedestrians may begin to cross the roadway in the direction of the indication.
- ✓ *flashing* DON'T WALK indication, means that a pedestrian shall not start to cross the roadway in the direction of the indication, but that any pedestrian who has partly completed their crossing shall continue to a sidewalk, or to a safety island.
- ✓ steady DON'T WALK indication, means that a pedestrian shall not enter the roadway in the direction of the indication.

Signal controllers used by MnDOT do not time the yellow vehicle indication concurrent with the flashing DON'T WALK. Because of this, a portion of the yellow interval may be included in the pedestrian clearance time (i.e., the pedestrian clearance time is equal to flashing DON'T WALK interval plus the yellow interval)

Walk

The MN MUTCD states, "Under normal conditions, the WALK interval should be at least 4 to 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb before the clearance interval is shown." Research indicates that queues (more than 24 people) requiring more than 7 seconds to discharge occur very rarely and will usually be found only in certain sections of large metropolitan areas. The minimum WALK interval under low volume (less than 10 pedestrians per cycle) conditions could possibly be lowered to 4 - 5 seconds but the importance of the inattentiveness factor should be also weighted in this decision.

Flashing Don't Walk

The duration of the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder at the end of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5 feet per second to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait.

The *flashing* DON'T WALK interval is determined by the following formula:

flashing DON'T WALK = D/R

D = Distance from the near curb or shoulder to at least the far side of the traveled way or to a median of greater than 6 feet.

R = Walking rate of 3.5 feet per second assumed walking rate unless special conditions (school kids, elderly or handicapped) require a slower walking rate.

When determining the distance, consideration should be given to the pedestrian's normal walking path. Pedestrian timing should consider the pedestrian walking to the nearest pedestrian and/or vehicle indication following a marked or unmarked crosswalk.

On median divided roadways, consideration should be given to providing sufficient time to the pedestrians to cross both roadways. A pedestrian's goal is to cross the total roadway and does not expect to stop at the

dividing median and wait till the next cycle. If the median is less than 6 feet wide the pedestrian should be provided sufficient time to cross both roadways as a median less than 6 feet wide is not considered a safe refuge island.

Normal walking speed is assumed to be 3.5 feet per second. This is as cited in the 2009 Federal MUTCD and will be the walking speed used in the pending update to the MN MUTCD. In selecting a walking rate, consideration must be given to the type of pedestrians, volume of pedestrians, intersection location and geometrics and overall signal operation.

Signal controllers used by MnDOT do not time the yellow vehicle indication concurrent with the flashing DON'T WALK. This is assuming minimum vehicle green time. The steady DON'T WALK is displayed at the onset of yellow to encourage any pedestrians still in the street to complete the crossing without delay. Because of this and a MN MUTCD Ruling No. IV-35, Pedestrian Clearance Interval Calculation, the yellow interval may be included in the pedestrian clearance time (i.e., the pedestrian clearance time is equal to flashing DON'T WALK interval plus the yellow interval). The *flashing* DON'T WALK interval could then be determined by the following formula:

flashing DON'T WALK = (D/R) - Yellow

However, the ruling also states, "Discretion should be used in utilizing the latitude afforded by Section 4E". Therefore, as a general practice, this should not be followed unless it is necessary to minimize the pedestrian timing. By subtracting the yellow interval, pedestrians may receive the steady DON'T WALK before they reach the far side of the farthest traveled lane. Engineering studies and judgment should be exercised in determining walking rates, distances and utilizing the yellow interval as part of the pedestrian clearance interval.

Pedestrian Timing Recommended Practice

Pertinent sections of the Federal MUTCD can be found on page 4-7.

For single roadways, and divided roadway with median island less than 6 feet wide and pedestrian indications on each side, the pedestrian will be provided time to cross from the near side curb or shoulder to the far side of the traveled way.

WALK = 7 seconds

(this may be reduced to 4 seconds if it is necessary to minimize pedestrian timing considering the other factors)

flashing DON'T WALK = (D/R)

(time should not be less than WALK time and the time may be reduced by the yellow interval if it is necessary to minimize pedestrian timing considering other factors)

D = Distance from the near curb or shoulder to at least the far side of the traveled way.

R = Walking rate of 3.5 feet per second is the assumed walking rate unless special conditions (school kids, elderly or handicapped) require a slower walking rate.

Divided Roadways

A divided road is one with a median island over 6 feet wide **and includes a pedestrian pushbutton in the median**. If a pushbutton is not in the median, the recommended practice above must be used (i.e., the pedestrian clearance interval must cross them completely from near side curb to far side curb).

Option 1 - Cross to Median Only

(Pedestrian indications present)

The WALK and *flashing* DON'T WALK should be determined as above. The crossing distance should be determined by using the longest distance from the curb or shoulder to the median. The pedestrian will be provided time to cross to the median on one cycle and time to cross the other side on the next cycle when the pedestrian push button is activated.

Option 2 - Cross Completely

In order for the pedestrian to cross the total roadway, the WALK indication must take the pedestrian past the median island before the flashing DON'T WALK is displayed. If the flashing DON'T WALK is displayed before the pedestrian reaches the median island, the pedestrian should stop at the median island and wait till the next WALK indication. The following special timing should allow the pedestrian to cross both roadways.

This timing also provides for a pedestrian that may start to cross the first roadway at the end of WALK. This pedestrian is provided enough flashing DON'T WALK to reach the median island and finish the crossing on the next WALK indication.

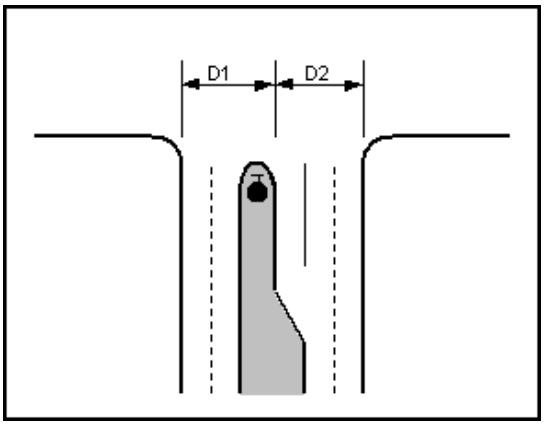
WALK = D1/R

flashing DON'T WALK = (D2/R)

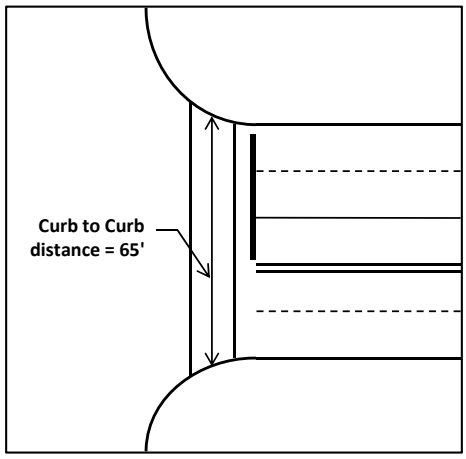
(this time may be less than the WALK time and the time may be reduced by the yellow time if it is necessary to minimize the pedestrian timing considering other factors)

Refer to **Exhibit 4-2** for D1 and D2 determination.

Exhibit 4-2 Pedestrian Crossing Distances



***Example**:* Consider the intersection shown below.



Assume a walking speed of 3.5 feet per second with no special pedestrian requirements.

The pedestrian clearance would then be, FDW = 65 feet / 3.5 feet per second = **19 seconds**

Accessible Pedestrian Signals (APS)

Refer to Section **4.11** on page **4-33** for information on APS.

Pedestrian Timing (2012 MN MUTCD)

The following information is from the 2012 MN MUTCD. The latest information can be found by visiting the OTST website, www.dot.state.mn.us/trafficeng/publ/mutcd/index.html.

HANDOUT

GUIDANCE:

Pedestrian signal head indications should be conspicuous and recognizable to pedestrians at all distances from the beginning of the controlled crosswalk to a point 10 feet from the end of the controlled crosswalk during both day and night.

For crosswalks where the pedestrian enters the crosswalk more than 100 feet from the pedestrian signal head indications, the symbols should be at least 9 inches high.

If the pedestrian signal indication is so bright that it causes excessive glare in nighttime conditions, some form of automatic dimming should be used to reduce the brilliance of the signal indication.

4E.5 Location and Height of Pedestrian Signal Heads

STANDARD:

Pedestrian signal heads shall be mounted with the bottom of the signal housing including brackets not less than 2.1 m (7 ft) nor more than 3 m (10 ft) above sidewalk level, and shall be positioned and adjusted to provide maximum visibility at the beginning of the controlled crosswalk.

If pedestrian signal heads are mounted on the same support as vehicular signal heads, there shall be a physical separation between them.

4E.6 Pedestrian Intervals and Signal Phases

STANDARD:

At intersections equipped with pedestrian signal heads, the pedestrian signal indications shall be displayed except when the vehicular traffic control signal is being operated in the flashing mode. At those times, the pedestrian signal indications shall not be displayed.

When the pedestrian signal heads associated with a crosswalk are displaying either a steady WALKING PERSON (symbolizing WALK) or a flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication, a steady or a flashing red signal indication shall be shown to any conflicting vehicular movement that is approaching the intersection or mid-block location perpendicular or nearly perpendicular to the crosswalk.

When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder.

A pedestrian change interval consisting of a flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication shall begin immediately following the WALKING PERSON (symbolizing WALK) signal indication.

Following the pedestrian change interval, a buffer interval consisting of a steady UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed for at least 3 seconds prior to the release of any conflicting vehicular movement. The sum of the time of the pedestrian change interval and the buffer interval shall not be less than the calculated pedestrian clearance time (see the following paragraphs starting with the first Guidance paragraph and ending with the second Standard paragraph). The buffer interval shall not begin later than the beginning of the red clearance interval, if used.

OPTION:

During the yellow change interval, the UPRAISED HAND (symbolizing DON'T WALK) signal indication may be displayed as either a flashing indication, a steady indication, or a flashing indication for an initial portion of the yellow change interval and a steady indication for the remainder of the interval.

SUPPORT:

Figure 4E-2 illustrates the pedestrian intervals and their possible relationships with associated vehicular signal phase intervals.

GUIDANCE:

Except as provided above, the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder at the end of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5ft per second, to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait.

OPTION:

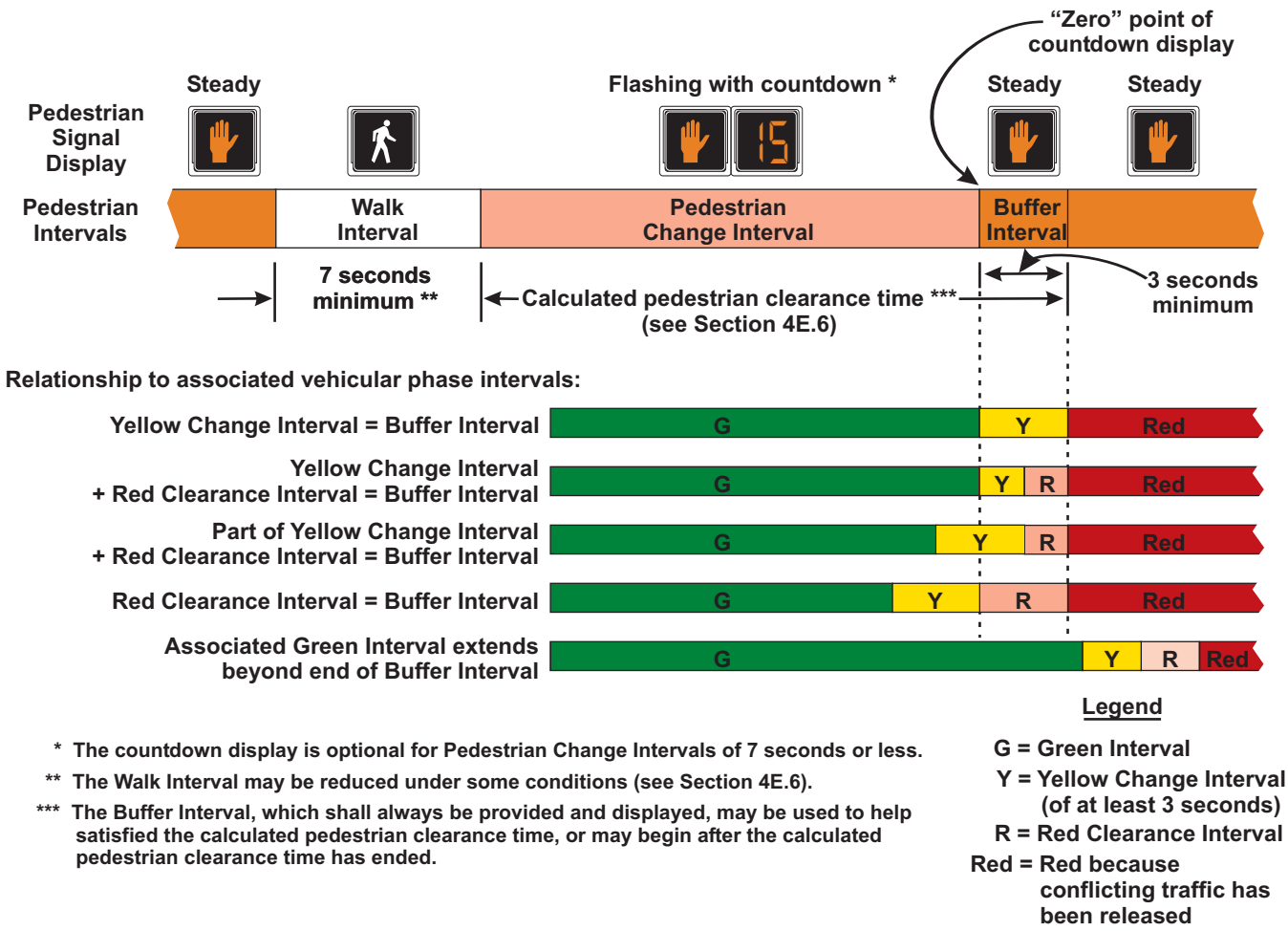
A walking speed of up to 4 feet per second may be used to evaluate the sufficiency of the pedestrian clearance time at locations where an extended pushbutton press function has been installed to provide slower pedestrians an opportunity to request and receive a longer pedestrian clearance time. Passive pedestrian detection may also be used to automatically adjust the pedestrian clearance time based on the pedestrian's actual walking speed or actual clearance of the crosswalk.

The additional time provided by an extended pushbutton press to satisfy pedestrian clearance time needs may be added to either the walk interval or the pedestrian change interval.

GUIDANCE:

Where pedestrians who walk slower than 3.5 ft per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 3.5 ft per second

HANDOUT



* The countdown display is optional for Pedestrian Change Intervals of 7 seconds or less.

** The Walk Interval may be reduced under some conditions (see Section 4E.6).

*** The Buffer Interval, which shall always be provided and displayed, may be used to help satisfied the calculated pedestrian clearance time, or may begin after the calculated pedestrian clearance time has ended.

Figure 4E-2. Pedestrian Intervals

should be considered in determining the pedestrian clearance time.

Except as provided in below, the walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins.

OPTION:

If pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used.

SUPPORT:

The walk interval is intended for pedestrians to start their crossing. The pedestrian clearance time is intended to allow pedestrians who started crossing during the walk interval to complete their crossing. Longer walk intervals are often used when the duration of the vehicular green phase associated with the pedestrian crossing is long enough to allow it.

GUIDANCE:

The total of the walk interval and pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the pedestrian detector (or, if no pedestrian detector is present, a location 6 feet from the face of the curb or from the edge of the pavement) at the beginning of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3 feet per second to the far side of the traveled way being crossed or to the median if a two-stage pedestrian crossing sequence is used. Any additional time that is required to satisfy the conditions of this paragraph should be added to the walk interval.

HANDOUT

OPTION:

On a street with a median of sufficient width for pedestrians to wait, a pedestrian clearance time that allows the pedestrian to cross only from the curb or shoulder to the median may be provided.

STANDARD:

Where the pedestrian clearance time is sufficient only for crossing from the curb or shoulder to a median of sufficient width for pedestrians to wait median-mounted pedestrian signals (with pedestrian detectors if actuated operation is used) shall be provided (see Sections 4E.8 and 4E.9) and signing such as the R10-3d sign (see Section 2B.52) shall be provided to notify pedestrians to cross only to the median to await the next WALKING PERSON (symbolizing WALK) signal indication.

GUIDANCE:

Where median-mounted pedestrian signals and detectors are provided, the use of accessible pedestrian signals (see Sections 4E.09 through 4E.13) should be considered.

OPTION:

During the transition into preemption, the walk interval and the pedestrian change interval may be shortened or omitted as described in Section 4D.27.

At intersections with high pedestrian volumes and high conflicting turning vehicle volumes, a brief leading pedestrian interval, during which an advance WALKING PERSON (symbolizing WALK) indication is displayed for the crosswalk while red indications continue to be displayed to parallel through and/or turning traffic, may be used to reduce conflicts between pedestrians and turning vehicles.

GUIDANCE:

If a leading pedestrian interval is used, the use of accessible pedestrian signals (see Sections 4E.09 through 4E.13) should be considered.

SUPPORT:

If a leading pedestrian interval is used without accessible features, pedestrians who are visually impaired can be expected to begin crossing at the onset of the vehicular movement when drivers are not expecting them to begin crossing.

GUIDANCE:

If a leading pedestrian interval is used, it should be at least 3 seconds in duration and should be timed to allow pedestrians to cross at least one lane of traffic or, in the case of a large corner radius, to travel far enough for pedestrians to establish their position ahead of the turning traffic before the turning traffic is released.

If a leading pedestrian interval is used, consideration should be given to prohibiting turns across the crosswalk during the leading pedestrian interval.

SUPPORT:

At intersections with pedestrian volumes that are so high that drivers have difficulty finding an opportunity to turn across the crosswalk, the duration of the green interval for a parallel concurrent vehicular movement is sometimes intentionally set to extend beyond the pedestrian clearance time to provide turning drivers additional green time to make their turns while the pedestrian signal head is displaying a steady UPRAISED HAND (symbolizing DONT WALK) signal indication after pedestrians have had time to complete their crossings.

4E.7 Countdown Pedestrian Signals

STANDARD:

All pedestrian signal heads used at crosswalks where the pedestrian change interval is more than 7 seconds shall include a pedestrian change interval countdown display in order to inform pedestrians of the number of seconds remaining in the pedestrian change interval.

OPTION:

Pedestrian signal heads used at crosswalks where the pedestrian change interval is 7 seconds or less may include a pedestrian change interval countdown display in order to inform pedestrians of the number of seconds remaining in the pedestrian change interval.

STANDARD:

Where countdown pedestrian signals are used, the countdown shall always be displayed simultaneously with the flashing UPRAISED HAND (symbolizing DONT WALK) signal indication displayed for that crosswalk.

Countdown pedestrian signals shall consist of Portland orange numbers that are at least 6 inches in height on a black opaque background. The countdown pedestrian signal shall be located immediately adjacent to the associated UPRAISED HAND (symbolizing DONT WALK) pedestrian signal head indication (see Figure 4E-1).

The display of the number of remaining seconds shall begin only at the beginning of the pedestrian change interval (flashing UPRAISED HAND). After the countdown displays zero, the display shall remain dark until the beginning of the next countdown.

The countdown pedestrian signal shall display the number of seconds remaining until the termination of the pedestrian change interval (flashing UPRAISED HAND). Countdown displays shall not be used during the walk interval or during the red clearance interval of a concurrent vehicular phase.

HANDOUT

GUIDANCE:

If used with a pedestrian signal head that does not have a concurrent vehicular phase, the pedestrian change interval (flashing UPRAISED HAND) should be set to be approximately 4 seconds less than the required pedestrian clearance time (see Section 4E.6) and an additional clearance interval (during which a steady UPRAISED HAND is displayed) should be provided prior to the start of the conflicting vehicular phase.

For crosswalks where the pedestrian enters the crosswalk more than 100 feet from the countdown pedestrian signal display, the numbers should be at least 9 inches in height.

Because some technology includes the countdown pedestrian signal logic in a separate timing device that is independent of the timing in the traffic signal controller, care should be exercised by the engineer when timing changes are made to pedestrian change intervals.

If the pedestrian change interval is interrupted or shortened as a part of a transition into a preemption sequence (see Section 4E.6), the countdown pedestrian signal display should be discontinued and go dark immediately upon activation of the preemption transition.

Operational requirements -
Compliance Date: December 22, 2006
Hardware -
Compliance Date: December 22, 2013

4E.8 Pedestrian Detectors

OPTION:

Pedestrian detectors may be pushbuttons or passive detection devices.

SUPPORT:

Passive detection devices register the presence of a pedestrian in a position indicative of a desire to cross, without requiring the pedestrian to push a button. Some passive detection devices are capable of tracking the progress of a pedestrian as the pedestrian crosses the roadway for the purpose of extending or shortening the duration of certain pedestrian timing intervals.

The provisions in this Section place pedestrian pushbuttons within easy reach of pedestrians who are intending to cross each crosswalk and make it obvious which pushbutton is associated with each crosswalk. These provisions also position pushbutton poles in optimal locations for installation of accessible pedestrian signals (see Sections 4E.09 through 4E.13). Information regarding reach ranges can be found in the "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)" (see Section 1A.11).

GUIDANCE:

If pedestrian pushbuttons are used, they should be capable of easy activation and conveniently located near each end of the crosswalks. Except as provided in the following 2 paragraphs, pedestrian pushbuttons should be located to meet all of the following criteria:

A. Unobstructed and adjacent to a level all-weather surface to provide access from a wheelchair;
B. Where there is an all-weather surface, a wheelchair accessible route from the pushbutton to the ramp;
C. Between the edge of the crosswalk line (extended) farthest from the center of the intersection and the side of a curb ramp (if present), but not greater than 5 feet from said crosswalk line;
D. Between 1.5 and 6 feet from the edge of the curb, shoulder, or pavement;
E. With the face of the pushbutton parallel to the crosswalk to be used; and
F. At a mounting height of approximately 3.5 feet, but no more than 4 feet, above the sidewalk.

Where there are constraints that make it impractical to place the pedestrian pushbutton adjacent to a level all-weather surface, the surface should be as level as feasible.

Where there are constraints that make it impractical to place the pedestrian pushbutton between 1.5 and 6 feet from the edge of the curb, shoulder, or pavement, it should not be farther than 10 feet from the edge of curb, shoulder, or pavement.

Except as provided in the following Option, where two pedestrian pushbuttons are provided on the same corner of a signalized location, the pushbuttons should be separated by a distance of at least 10 feet.

OPTION:

Where there are constraints on a particular corner that make it impractical to provide the 10-foot separation between the two pedestrian pushbuttons, the pushbuttons may be placed closer together or on the same pole

STANDARD:

Signs (see Section 2B. 52) shall be mounted adjacent to or integral with pedestrian pushbuttons, explaining their purpose and use.

OPTION:

At certain locations, a supplemental sign in a more visible location may be used to call attention to the pedestrian pushbutton.

STANDARD:

The positioning of pedestrian pushbuttons and the legends on the pedestrian pushbutton signs shall clearly

HANDOUT

indicate which crosswalk signal is actuated by each pedestrian pushbutton.

If the pedestrian clearance time is sufficient only to cross from the curb or shoulder to a median of sufficient width for pedestrians to wait and the signals are pedestrian actuated, an additional pedestrian detector shall be provided in the median.

GUIDANCE:

The use of additional pedestrian detectors on islands or medians where a pedestrian might become stranded should be considered.

If used, special purpose pushbuttons (to be operated only by authorized persons) should include a housing capable of being locked to prevent access by the general public and do not need an instructional sign.

STANDARD:

If used, a pilot light or other means of indication installed with a pedestrian pushbutton shall not be illuminated until actuation. Once it is actuated, the pilot light shall remain illuminated until the pedestrian's green or WALKING PERSON (symbolizing WALK) signal indication is displayed.

If a pilot light is used at an accessible pedestrian signal location (see Sections 4E.09 through 4E.13), each actuation shall be accompanied by the speech message "wait."

OPTION:

At signalized locations with a demonstrated need and subject to equipment capabilities, pedestrians with special needs may be provided with additional crossing time by means of an extended pushbutton press.

STANDARD:

If additional crossing time is provided by means of an extended pushbutton press, a PUSH BUTTON FOR 2 SECONDS FOR EXTRA CROSSING TIME (R10-32P) plaque (see Figure 2B-26) shall be mounted adjacent to or integral with the pedestrian pushbutton.

4E.9 Accessible Pedestrian Signals and Detectors - General

SUPPORT:

Accessible pedestrian signals and detectors provide information in non-visual formats (such as audible tones, speech messages, and/or vibrating surfaces).

The primary technique that pedestrians who have visual disabilities use to cross streets at signalized locations is to initiate their crossing when they hear the traffic in front of them stop and the traffic alongside them begin to move, which often corresponds to the onset of the green interval. The existing environment is often not sufficient to provide the information that pedestrians who have visual disabilities need to cross a roadway at a signalized location.

GUIDANCE:

If a particular signalized location presents difficulties for pedestrians who have visual disabilities to cross the roadway, an engineering study should be conducted that considers the needs of pedestrians in general, as well as the information needs of pedestrians with visual disabilities. The engineering study, should consider the following factors:

A. Potential demand for accessible pedestrian signals;
B. A request for accessible pedestrian signals;
C. Traffic volumes during times when pedestrians might be present, including periods of low traffic volumes or high turn-on-red volumes;
D. The complexity of traffic signal phasing (such as split phases, protected turn phases, leading pedestrian intervals, and exclusive pedestrian phases); and
E. The complexity of intersection geometry.

SUPPORT:

The factors that make crossing at a signalized location difficult for pedestrians who have visual disabilities include: increasingly quiet cars, right turn on red (which masks the beginning of the through phase), continuous right-turn movements, complex signal operations, traffic circles, and wide streets. Further, low traffic volumes might make it difficult for pedestrians who have visual disabilities to discern signal phase changes.

Local organizations, providing support services to pedestrians who have visual and/or hearing disabilities, can often act as important advisors to the traffic engineer when consideration is being given to the installation of devices to assist such pedestrians. Additionally, orientation and mobility specialists or similar staff also might be able to provide a wide range of advice. The U.S. Access Board's (www.access-board.gov) provides technical assistance for making pedestrian signal information available to persons with visual disabilities (see Page i for the address for the U.S. Access Board).

STANDARD:

When used, accessible pedestrian signals shall be used in combination with pedestrian signal timing. The information provided by an accessible pedestrian signal shall clearly indicate which pedestrian crossing is served by each device.

Under stop-and-go operation, accessible pedestrian signals shall not be limited in operation by the time of day or day of week.

HANDOUT

OPTION:

Accessible pedestrian signal detectors may be pushbuttons or passive detection devices.

At locations with pretimed traffic control signals or non-actuated approaches, pedestrian pushbuttons may be used to activate the accessible pedestrian signals.

SUPPORT:

Accessible pedestrian signals are typically integrated into the pedestrian detector (pushbutton), so the audible tones and/or messages come from the pushbutton housing. They have a pushbutton locator tone and tactile arrow, and can include audible beaconing and other special features.

OPTION:

The name of the street to be crossed may also be provided in accessible format, such as Braille or raised print. Tactile maps of crosswalks may also be provided.

SUPPORT:

Specifications regarding the use of Braille or raised print for traffic control devices can be found in the "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)" (see Section 1A.11).

STANDARD:

At accessible pedestrian signal locations where pedestrian pushbuttons are used, each pushbutton shall activate both the walk interval and the accessible pedestrian signals.

4E.10 Accessible Pedestrian Signals and Detectors - Location

SUPPORT:

Accessible pedestrian signals that are located as close as possible to pedestrians waiting to cross the street provide the clearest and least ambiguous indication of which pedestrian crossing is served by a device.

GUIDANCE:

Pushbuttons for accessible pedestrian signals should be located in accordance with the provisions of Section 4E.8 and should be located as close as possible to the crosswalk line furthest from the center of the intersection and as close as possible to the curb ramp.

STANDARD:

If two accessible pedestrian pushbuttons are placed less than 10 feet apart or on the same pole, each accessible pedestrian pushbutton shall be provided with the following features (see Sections 4E.11 through 4E.13):

A. A pushbutton locator tone,

B. A tactile arrow,

C. A speech walk message for the WALKING PERSON (symbolizing WALK) indication, and

D. A speech pushbutton information message.

If the pedestrian clearance time is sufficient only to cross from the curb or shoulder to a median of sufficient width for pedestrians to wait and accessible pedestrian detectors are used, an additional accessible pedestrian detector shall be provided in the median.

4E.11 Accessible Pedestrian Signals and Detectors - Walk Indications

SUPPORT:

Technology that provides different sounds for each non-concurrent signal phase has frequently been found to provide ambiguous information. Research indicates that a rapid tick tone for each crossing coming from accessible pedestrian signal devices on separated poles located close to each crosswalk provides unambiguous information to pedestrians who are blind or visually impaired. Vibrotactile indications provide information to pedestrians who are blind and deaf and are also used by pedestrians who are blind or who have low vision to confirm the walk signal in noisy situations.

STANDARD:

Accessible pedestrian signals shall have both audible and vibrotactile walk indications.

Vibrotactile walk indications shall be provided by a tactile arrow on the pushbutton (see Section 4E.12) that vibrates during the walk interval.

Accessible pedestrian signals shall have an audible walk indication during the walk interval only. The audible walk indication shall be audible from the beginning of the associate crosswalk.

The accessible walk indication shall have the same duration as the pedestrian walk signal except when the pedestrian signal rests in walk.

GUIDANCE:

If the pedestrian signal rests in walk, the accessible walk indication should be limited to the first 7 seconds of the walk interval. The accessible walk indication should be recalled by a button press during the walk interval provided that the crossing time remaining is greater than the pedestrian change interval.

STANDARD:

Where two accessible pedestrian signals are separated by a distance of at least 10 feet, the audible walk indication

HANDOUT

shall be a percussive tone. Where two accessible pedestrian signals on one corner are not separated by a distance of at least 10 feet, the audible walk indication shall be a speech walk message.

Audible tone walk indications shall repeat at eight to ten ticks per second. Audible tones used as walk indications shall consist of multiple frequencies with a dominant component at 880 Hz.

GUIDANCE:

The volume of audible walk indications and pushbutton locator tones (see Section 4E.12) should be set to be a maximum of 5 dBA louder than ambient sound, except when audible beaconing is provided in response to an extended pushbutton press.

STANDARD:

Automatic volume adjustment in response to ambient traffic sound level shall be provided up to a maximum volume of 100 dBA.

GUIDANCE:

The sound level of audible walk indications and pushbutton locator tones should be adjusted to be low enough to avoid misleading pedestrians who have visual disabilities when the following conditions exist:

A. Where there is an island that allows unsignalized right turns across a crosswalk between the island and the sidewalk.
B. Where multi-leg approaches or complex signal phasing require more than two pedestrian phases, such that it might be unclear which crosswalk is served by each audible tone.
C. At intersections where a diagonal pedestrian crossing is allowed, or where one street receives a WALKING PERSON (symbolizing WALK) signal indication simultaneously with another street.

OPTION:

An alert tone, which is a very brief burst of high-frequency sound at the beginning of the audible walk indication that rapidly decays to the frequency of the walk tone, may be used to alert pedestrians to the beginning of the walk interval.

SUPPORT:

An alert tone can be particularly useful if the walk tone is not easily audible in some traffic conditions.

Speech walk messages communicate to pedestrians which street has the walk interval. Speech messages might be either directly audible or transmitted, requiring a personal receiver to hear the message. To be a useful system, the words and their meaning need to be correctly understood by all users in the context of the street environment where they are used. Because of this, tones are the preferred means of providing audible walk indications except where two accessible pedestrian signals on one corner are not separated by a distance of at least 10 feet.

If speech walk messages are used, pedestrians have to know the names of the streets that they are crossing in order for the speech walk messages to be unambiguous. In getting directions to travel to a new location, pedestrians with visual disabilities do not always get the name of each street to be crossed. Therefore, it is desirable to give users of accessible pedestrian signals the name of the street controlled by the pushbutton. This can be done by means of a speech pushbutton information message (see Section 4E.13) during the flashing or steady UPRAISED HAND intervals, or by raised print and Braille labels on the pushbutton housing.

By combining the information from the pushbutton message or Braille label, the tactile arrow aligned in the direction of travel on the relevant crosswalk, and the speech walk message, pedestrians with visual disabilities are able to correctly respond to speech walk messages even if there are two pushbuttons on the same pole.

STANDARD:

If speech walk messages are used to communicate the walk interval, they shall provide a clear message that the walk interval is in effect, as well as to which crossing it applies. Speech walk messages shall be used only at intersections where it is technically infeasible to install two accessible pedestrian signals at one corner separated by a distance of at least 10 feet.

Speech walk messages that are used at intersections having pedestrian phasing that is concurrent with vehicular phasing shall be patterned after the model: "Broadway. Walk sign is on to cross Broadway."

Speech walk messages that are used at intersections having exclusive pedestrian phasing shall be patterned after the model: "Walk sign is on for all crossings."

Speech walk messages shall not contain any additional information, except they shall include designations such as "Street" or "Avenue" where this information is necessary to avoid ambiguity at a particular location.

GUIDANCE:

Speech walk messages should not state or imply a command to the pedestrian, such as "Cross Broadway now." Speech walk messages should not tell pedestrians that it is "safe to cross," because it is always the pedestrian's responsibility to check actual traffic conditions.

HANDOUT

STANDARD:

A speech walk message is not required at times when the walk interval is not timing, but, if provided:

A. It shall begin with the term "wait."
B. It need not be repeated for the entire time that the walk interval is not timing.

If a pilot light (see Section 4E.8) is used at an accessible pedestrian signal location, each actuation shall be accompanied by the speech message "wait."

OPTION:

Accessible pedestrian signals that provide speech walk messages may provide similar messages in languages other than English, if needed, except for the terms "walk sign" and "wait."

STANDARD:

Following the audible walk indication, accessible pedestrian signals shall revert to the pushbutton locator tone (see Section 4E.12) during the pedestrian change interval.

4E.12 Accessible Pedestrian Signals and Detectors - Tactile Arrows and Locator Tones

STANDARD:

To enable pedestrians who have visual disabilities to distinguish and locate the appropriate pushbutton at an accessible pedestrian signal location, pushbuttons shall clearly indicate by means of tactile arrows which crosswalk signal is actuated by each pushbutton. Tactile arrows shall be located on the pushbutton, have high visual contrast (light on dark or dark on light) and shall be aligned parallel to the direction of travel on the associated crosswalk.

An accessible pedestrian pushbutton shall incorporate locator tone.

SUPPORT:

A pushbutton locator tone is a repeating sound that informs approaching pedestrians that a pushbutton to actuate pedestrian timing or receive additional information exists, and that enables pedestrians with visual disabilities to locate the pushbutton.

STANDARD:

Pushbutton locator tones shall have a duration of 0.15 seconds or less and shall repeat at 1-second intervals.

Pushbutton locator tones shall be deactivated when the traffic control signal is operating in a flashing mode. This requirement shall not apply to traffic control signals or pedestrian hybrid beacons that are activated from a flashing or dark mode to a stop-and-go mode by pedestrian actuations.

Pushbutton locator tones shall be intensity responsive to ambient sound, and be audible 1.8 to 3.7 m (6 to 12 ft) from the pushbutton, or to the building line, whichever is less.

SUPPORT:

Section 4E.11 contains additional provisions regarding the volume and sound level of pushbutton locator tones.

4E.13 Accessible Pedestrian Signals and Detectors - Extended Pushbutton Press Features

OPTION:

Pedestrians may be provided with additional features such as increased crossing time, audible beaconing, or a speech pushbutton information message as a result of an extended pushbutton press.

STANDARD:

If an extended pushbutton press is used to provide any additional feature(s), a pushbutton press of less than one second shall actuate only the pedestrian timing and any associated accessible walk indication, and a pushbutton press of two seconds or more shall actuate the pedestrian timing, any associated accessible walk indication, and any additional feature(s).

If additional crossing time is provided by means of an extended pushbutton press, a PUSH BUTTON FOR 2 SECONDS FOR EXTRA CROSSING TIME (R10-32P) plaque (see Figure 2B-26) shall be mounted adjacent to or integral with the pedestrian pushbutton.

SUPPORT:

Audible beaconing is the use of an audible signal in such a way that pedestrians with visual disabilities can home in on the signal that is located on the far end of the crosswalk as they cross the street.

Not all crosswalks at an intersection need audible beaconing; audible beaconing can actually cause confusion if used at all crosswalks at some intersections. Audible beaconing is not appropriate at locations with channelized turns or split phasing, because of the possibility of confusion.

GUIDANCE:

Audible beaconing should only be considered following an engineering study at:

A. Crosswalks longer than 70 feet, unless they are divided by a median that has another accessible pedestrian signal with a locator tone;
B. Crosswalks that are skewed;
C. Intersections with irregular geometry, such as more than four legs;

D. Crosswalks where audible beaconing is requested by an individual with visual disabilities; or
E. Other locations where a study indicates audible beaconing would be beneficial.

OPTION:

Audible beaconing may be provided in several ways, any of which are initiated by an extended pushbutton press.

STANDARD:

If audible beaconing is used, the volume of the pushbutton locator tone during the pedestrian change interval of the called pedestrian phase shall be increased and operated in one of the following ways:

A. The louder audible walk indication and louder locator tone comes from the far end of the crosswalk, as pedestrians cross the street,
B. The louder locator tone comes from both ends of the crosswalk, or
C. The louder locator tone comes from an additional speaker that is aimed at the center of the crosswalk and that is mounted on a pedestrian signal head.

OPTION:

Speech pushbutton information messages may provide intersection identification, as well as information about unusual intersection signalization and geometry, such as notification regarding exclusive pedestrian phasing, leading pedestrian intervals, split phasing, diagonal crosswalks, and medians or islands.

STANDARD:

If speech pushbutton information messages are made available by actuating the accessible pedestrian signal detector, they shall only be actuated when the walk interval is not timing. They shall begin with the term "Wait," followed by intersection identification information modeled after: "Wait to cross Broadway at Grand." If information on intersection signalization or geometry is also given, it shall follow the intersection identification information.

GUIDANCE:

Speech pushbutton information messages should not be used to provide landmark information or to inform pedestrians with visual disabilities about detours or temporary traffic control situations.

SUPPORT:

Additional information on the structure and wording of speech pushbutton information messages is included in ITE's "Electronic Toolbox for Making Intersections More Accessible

HANDOUT

4.6 Initial Timing

Minimum Initial

The minimum initial time is the minimum assured green that is displayed. It is established to allow vehicles stopped between the detector on the approach and the stop line to get started and move into the intersection. Therefore, timing of this interval depends on the location of the detector and the number of vehicles that can be stored between the detector and the stop line. Consideration must be given to pedestrian timing, density operations, controller type and detection design when determining this setting. When there are no pedestrian provisions (indications or pushbuttons), the minimum assured green must be equal to the minimum pedestrian timing (walk + pedestrian clearance).

Non-density operation. In non-density operation the minimum initial green must be long enough to guarantee that vehicles stored between the detector and the stop line will clear the intersection before the clearance intervals terminate the movement. If stop line extending detection is used, the minimum initial green time should be set as for a density operation.

Density operation. In density operation the minimum initial green should be set low to clear a minimum of vehicles expected during light volume. Density operation has another timed interval that adds initial time per vehicle arriving on red for that approach. The initial green should not be set to low as to display an unexpected short green.

Minimum Initial (Density operation)

Major approach	=	15 seconds
		20 seconds (45 mph or above)
Minor approach	=	7-10 seconds (consider the lower values when split phasing is used)
Protected Left turn	=	7 seconds
Protected/Permissive	=	5 seconds

(Non-density operation)

Minimum initial green = 3 + 2n

n = Number of vehicles that can be stored between the stop line and the far detector in one lane. This is determined by dividing the distance between the stop line and the detector by 25. 25 is the average vehicle length plus headway in feet.

4.7 Density Features

Added Initial

Added initial is sometimes referred to as variable initial. This feature increases the minimum assured green time (minimum initial) so it will be long enough to serve the actual number of vehicles waiting for the green between the stop line and the detector.

This interval is generally used on phases for higher speed approaches where the detectors are placed quite a distance from the stop line (resulting in unacceptably long minimum initial requirements). This feature allows the minimum initial to be set low for light volumes. Vehicles crossing the detector when the phase is red will add time to the minimum assured green, so that when the phase is served, the minimum assured green will be long enough to serve the actual number of vehicles waiting for the green.

Consideration should be given to the number of lanes and detectors, distance from the stop line to detector, number of right turn vehicles, approach grades, type of controller, etc.

Field observation is very important in determining this setting.

Most controllers used in MnDOT utilize the function settings of "Actuations Before Added Initial" and "Added Initial Per Actuation" to determine Added Initial.

This is calculated by the following:

D/25 x 2.1 + 3

Example: If detector is 400' from stop line, then

400/25 x 2.1 + 3 = 16 x 2.1 + 3 = 36.6 seconds

Actuations Before Added Initial (Traconex) is the number of vehicles which can be adequately served by the time set on the minimum initial

	One Lane	Two Lanes
15 second Minimum Initial	6	10
20 second Minimum Initial	8	14

This is determined by: (minimum initial - 3) / 2

Two lane is 1.75 of one lane.

Added Initial Per Actuation is the amount of time that each vehicle crossing the detector on red should add to the minimum assured green.

One Lane: 2.0 seconds per actuation

Two Lane: 1.5 seconds per actuation

Passage Time

This function setting is the same for non-density and density operation. This setting should be the number of seconds required for a vehicle moving at the approach speed to travel from the detector to the stop line. The passage time serves two purposes. It is the passage time from the detector to the stop line and the allowable time gap between actuations that will cause the green to remain on that approach. As long as vehicle detections come at shorter intervals than the passage time (allowable gap), the green will be retained on that phase. In the density operation, the allowable gap is reduce by another timing feature.

If the passage interval is too short, quick stops may result as well as terminating the green before the vehicular movement has been adequately served. If the passage interval is set too long, excessive delays will result as well as safety problems due to improperly timed last vehicle intervals.

Passage Time = $^{D}/_{1.47S}$ (general range is 2.0 - 8.0 seconds)

D = Distance from the stop line to back detector, if single point detection. Distance (greatest distance) between stop line and/or detectors, if multiple detection.

S = Posted speed limit in mph

GAP REDUCTION - Density Feature

This feature reduces the passage time and as a result reduces the allowable time gap between actuations that will cause the green to remain on that approach.

When a phase is green the time between vehicles to terminate that phase starts out at amount of time set for the passage time (i.e., successive actuations must be closer together than the passage time to extend the green). After the phase has been green for some time, it becomes desirable to terminate the phase on smaller distances between vehicles. This is done to reduce the probability of the phase being terminated at the maximum time. **When a phase terminates at maximum time there is no dilemma zone protection**. This feature is generally used on phases for higher speed approaches where the detectors are placed quite a distance from the stop line (resulting in long passage timing).

Most controller used by MnDOT utilize the time setting of "Time Before Reduction", "Time To Reduce" and "Minimum Gap"

Time Before Reduction establishes the time before the passage time (allowable gap) begins to reduce.

Time To Reduce establishes the time in which the allowable gap is reduced from the passage time to the minimum gap, after the time before reduction has expired.

Minimum Gap establishes the minimum value to which the allowable gap between actuations can be reduced to upon expiration of the time to reduce.

Generally the minimum gap should not be set lower than 2 seconds. This is the average headway between vehicles and is approximately the time it takes a vehicle to travel from the detector through the dilemma zone. The amount of time into the green to reduce to the minimum gap should be set at about 2/3 of the maximum time. The allowable gap will gradually reduce in that time frame. Therefore, the last 1/3 of the maximum green would be extended only by tightly spaced vehicles.

Time Before Reduction

This should be set for 1/3 maximum time.

Time To Reduce

This should be set for 1/3 maximum time.

Minimum Gap

Minimum Gap = Passage time minus the time in seconds between the stop line and the end of the dilemma zone (MnDOT uses 2.0)

Note: Gap reduction is normally not used when stop bar detectors exist. Gap reduction with stop bar detectors require special detector functions and timings.

During moderate flow conditions a well-timed actuated signal should terminate due to gap-out rather than due to max-out. The goal of good green timing should be to terminate the green indication on gap out and to max out only under heavy traffic conditions (tightly spaced vehicles).

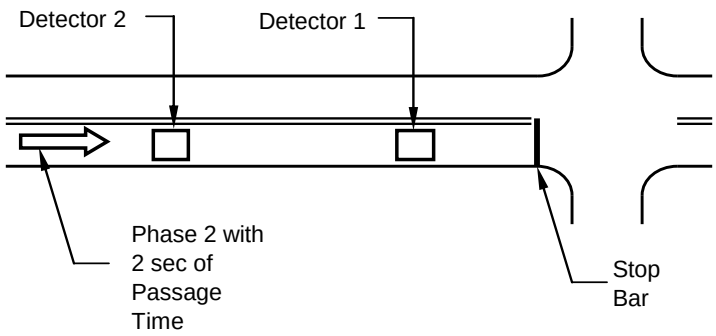
Detector Extend

The sections above discuss per phase controller settings. That is, the setting in the controller applies to the given movement/phase. There are also additional functions that allow this to be extended with the detectors. Some users will use a "per phase" extension and an additional extension "by detector".

Refer to the following image. In this example, the passage time is set to 2 seconds. This 2 seconds may be adequate to get a vehicle from Detector 1 through or to the intersection. However, the 2 seconds of time

may not be enough to get a vehicle from Detector 2 to Detector 1. Instead of increasing the Passage Time, which would be used by both detectors, a special extension of X seconds could be added to Detector 2.

Exhibit 4-3 Detector Extend Example



4.8 Maximum Green

Careful capacity analysis must be made to control peak hour cycle lengths and phase green times. The critical movement analysis (CMA) procedures will be used to establish these maximum green time settings.

Most controllers used by MnDOT can have two or more maximum green times programmed. The second maximum time can be put into effect by the controller time clock.

Outlined below is the basic procedure to determine maximum green time per phase. An analysis should be done for both AM and PM peak hours or other peak time.

- ✓ From the AM and PM peak hour turning movement counts, take the 15 minute peak and multiply it by 4 to get the adjusted peak hour volume. If only hourly volumes are available divide the hourly volume by the peak hour factor. If a peak hour factor is not available use a 0.9 factor.
- ✓ Select the critical phase volume and sum them for a total intersection critical phase volume. All phase volumes should be per lane volumes.
- ✓ Use this volume to select the first approximation for cycle length from the tables on the following page.
- ✓ Once the cycle length has been determined, determine cycles per hour which is equal to 3600/cycle length.
- ✓ Calculate the number of vehicles that are required to handle per cycle per phase. No. of vehicles = volume/cycles per hour
- ✓ Apply 3 + 2.1n formula to get the required phase green time to handle vehicles. n - number of vehicles arrived at in step 5. The 3 factor is the start up delay (2.5 seconds is recommended by ITE) and the 2.1 is for a 2.1 second headway per vehicle.
- ✓ Take the calculated phase green time and multiple by 1.5 and round to the nearest 5 seconds. This factor is applied because these calculation apply basically to fixed time controllers and this factor increases the time to allow for fluctuations in vehicle demand that an actuated controller is designed to handle. This should allow the phase to terminate on a gap in traffic at 2/3 of maximum time as discussed earlier rather than maxing out.
- ✓ Review these phase green times and adjust for intersection characteristics and how intersection should operate to arrive at the maximum green timing per phase. If green time demand is more than a 180 second cycle length, cycle length and phase green times should be reduced proportionately.

During moderate flow conditions a well-timed actuated signal will seldom terminate the green because the maximum green has timed out, it should terminate on gap out.

Optional check on cycle length:

The cycle length should also be compared to the Webster equation for calculation of cycle length. This equation for optimum cycle length that minimizes delay is as follows:

$$C = {}^{(1.5L + 5)} / {}_{(1.0 - Y)}$$

NOTE:

C = optimum cycle length, seconds

L = unusable time per cycle, seconds = nl + R

n = number of phases

l = average lost time per phase, seconds

R = Total all-red time per cycle, seconds = assumed to be the yellow and all-red

Y = sum of critical approach volume/saturation flow in each phase, assume saturation flow rate as 1600 vehicles per hour

The calculated cycle should fall within range of .75C and 1.5C as determined by the Webster formula. It has been determined that cycle lengths within this range do not significantly affect delay.

Consideration should be given to utilizing software in determining maximum green times.

Approximation for Cycle Length

Typical Maximum Green Interval

Left turn phase	10 - 45 seconds
Minor approach phase	20 - 75 seconds
Density operation	30 - 75 seconds
Major approach phase	30 - 120 seconds
Density operation under 45 mph	45 - 120 seconds
45 mph and over	60 - 120 seconds

Typical Minimum Cycle Length

2 phase signal	45 seconds
5 phase signal	60 seconds
8 phase signal	75 seconds

Typical Maximum Cycle Length = 180 seconds

SUM OF CRITICAL VOLUME	2 PHASE	5 PHASE	8 PHASE
700	45	60	90
800	60	75	105
900	60	75	105
1000	75	90	105
1100	75	90	105
1200	90	105	120
1300	105	120	135
1400	120	135	150
1500	135	150	165
1600	150	165	180
1700	165	180	180
1800	180	180	180

4.9 Phase Change Interval

The MN MUTCD states that the exclusive function of the steady yellow interval shall be to warn traffic of an impending change of right-of-way assignment. The yellow vehicle change interval should have a range of approximately 3 to 6 seconds. Generally the longer intervals are appropriate to higher approach speeds. The yellow vehicle change interval should be followed by a short all-way red clearance interval, of sufficient duration to permit the intersection to clear before cross traffic is released.

Minnesota Traffic Laws state that vehicular traffic facing a yellow indication is warned that the related green movement is being terminated or that the red indication will be exhibited immediately thereafter when vehicular traffic shall not enter the intersection. Therefore, the yellow and all-red intervals advise that the green interval is about to end and either;

- ✓ permits the vehicle to come to a safe stop at the stop line, or
- ✓ allows vehicles that are to near the intersection to stop or safely clear the intersection.

Yellow Timing

The following formulas may be used to determine the yellow time. This is based on the Institute of Transportation Engineers equation for yellow clearance interval.

$$Y = t + \frac{1.467\,v}{2(a + 32.2g)}$$

English

Y = Yellow Interval in seconds

t = perception-reaction time, assumed to be 1 second

v = posted speed, miles per hour

a = deceleration rate, assumed to be 10 feet/sec^2

g = + or - grade of approach in percent/100

Exhibit 4-4 Yellow Timing Values

Posted Speed	Percent Grade							MnDOT
	+3	+2	+1	Level	-1	-2	-3	
25	2.7	2.7	2.8	2.8	2.9	3.0	3.0	**3.0**
30	3.0	3.1	3.1	3.2	3.3	3.4	3.4	**3.5**
35	3.3	3.4	3.5	3.6	3.7	3.7	3.8	**4.0**
40	3.7	3.8	3.8	3.9	4.0	4.1	4.3	**4.0**
45	4.0	4.1	4.2	4.3	4.4	4.5	4.7	**4.5**
50	4.4	4.5	4.6	4.7	4.8	4.9	5.1	**5.0**
55	4.7	4.8	4.8	5.0	5.2	5.3	5.5	**5.5**
60	5.0	5.1	5.1	5.4	5.6	5.7	5.9	**6.0**
65	5.4	5.5	5.5	5.8	5.9	6.1	6.3	**6.0**

Yellow Interval for Left Turns

MnDOT will often use 25 mph (or a value of 3.0 seconds) for left turns. If timing a single point urban interchange (SPUI) or an intersection with a wide, sweeping radius, assume a speed of 35 mph. For information on the yellow interval for a FYA, refer to page 4-26.

All Red

The following formulas may be used to determine the red time. This is based on the Institute of Transportation Engineers (ITE) equation for red clearance interval.

$$R = \frac{w + L}{1.467v}$$

English

R = All red clearance interval in seconds

w = width of intersection, stop line to ~~center~~ the end of the farthest conflicting lane

l = length of vehicle, assumed to be 20 feet

v = posted speed in mile per hour

Exhibit 4-5 All Red Times

Posted Speed	Width of Intersection								
	30	40	50	60	70	80	90	100	110
25	1.4	1.6	1.9	2.2	2.5	2.7	3.0	3.3	3.5
30	1.1	1.4	1.6	1.8	2.0	2.3	2.5	2.7	3.0
35	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5
40	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2
45	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0
50	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8
55	0.6	0.7	0.9	1.0	1.1	1.2	1.4	1.5	1.6
60	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5

These formulas are general and should only be used as a guide. Other factors at an intersection (such as approach grades, visibility, truck traffic and local traffic characteristics) should be considered. It is important that approach grades and truck traffic are considered in determining the yellow and red intervals. The yellow interval must not be too short (causing quick stops and/or red violations) nor too long (causing regular "driving of the yellow").

The all-red should be in the range of 1 to 5 seconds.

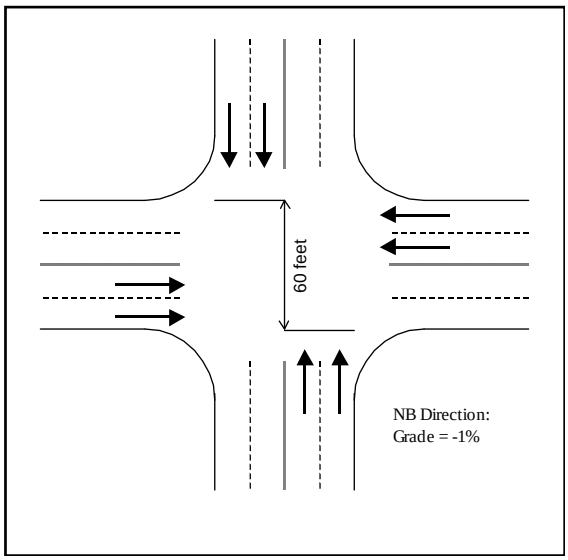
All Red for Left Turns

MnDOT will often use 25 mph for left turns. If timing a single point urban interchange (SPUI) or an intersection with a wide, sweeping radius, assume a speed of 35 mph.

The width of the intersection, w, for a left turn is commonly determined from a scaled intersection drawing. This distance (w) is measured along the path of the left turn vehicle from the stop to the end of the farthest conflicting lane.

For information on the all red interval for a FYA, refer to page 4-26.

***Example**:* Consider the intersection shown in the figure below.



Assume the following:

t = 1.0 seconds

v = 45 mph

a = 10 feet per second

l = 20 feet

g = -1 percent

$$Y + R = 1.0 + \frac{1.467\,(45)}{2\{10 + 32.2(-0.01)\}} + \frac{60 + 20}{1.467\,(45)}$$

Y + AR = 1.0 + 3.41 + 1.21 = 5.62 seconds

Use,

Yellow = 4.4 seconds and All Red = 1.2 seconds

4.10 Flashing Yellow Arrow Operation

FYA Yellow and All-Red Times

Yellow time for clearing the green arrow for leading or lagging left turns will be the same as the current agency standard for left-turn operation (see page **4-22**).

Yellow time for clearing the FYA will be the opposing through yellow time (3.5 to 6.0 sec) as the FYA will be driven by an overlap with the opposing through phase.

When transitioning from a protected left turn to a permissive left turn in protected/permissive operations, the all-red time will be a minimum of 2 seconds with the red arrow being shown.

Permissive Operation When Adjacent through Head is Red

The FYA display will allow for a permissive operation when the adjacent through head is red (see **Exhibit 3-13**). This was not possible with the 5-section protected/permissive head. This situation could occur if one left turn movement runs longer than the opposing left turn movement and the shorter left turn will get the permissive flashing yellow arrow while the opposing left turn is causing the adjacent through head to still be red.

Adjacent through heads may also be red when lagging lefts are used with protected/permissive operation. This is also something that wasn't possible with the 5-section protected/permissive head as it would cause a "left-turn trap" (See the discussion on "**Left Turn Trapping**" on page **3-29**). The FYA head doesn't cause a left-turn trap because it is an exclusive head for left turning vehicles (see the topic "Flashing Yellow Arrow and the Left Turn Trap" on page **3-31**). However, it is a new operation for motorists in that they will be looking for gaps while yielding on the flashing yellow arrow while the adjacent through head goes yellow due to the opposing protected/permissive lagging left. The flashing yellow arrow will continue to operate even though the adjacent head goes red and motorists will need to continue to yield to oncoming traffic.

Varying FYA Head between Protected, Protected/Permissive, and Permissive Operation

As discussed earlier, the FYA can be considered a variable operation signal indication. Consider the following items:

- ✓ All FYA signals may vary operation between protected, protected/permissive, and permissive operation at various times of the day and night.
- ✓ Each signal approach will need to be analyzed individually to determine the time-of-day FYA operation by considering the following criteria:
    a) Cross-product volumes of left turns and opposing throughs at various times of day
    b) Speed limit
    c) Sight distance limitations
    d) Number of opposing through lanes
    e) Double left turn lanes or single left turn lanes
    f) Opposing left turn lane offset
    g) Cross street or mainline approach
    h) Comprehensive left turn crash analysis of approaches with similar characteristics

The following sections are general guidelines on determining when to use the various types of operation for the FYA indication. In all cases, engineering judgment must be exercised and the information below used as guidance.

Test for Protected Only Operation 24 Hours per Day

In some cases, the left turn indication should run in the most restrictive Protected-Only mode 24 hours per day. Refer to Exhibit 4-6 for the Protected Only Left Turn Operation Guidelines. If the answer to question 1 or 2 is "yes", then protected operation should be used throughout the day.

If the answer is "yes" to any of the questions in Part 1, then Protected-Only operation is suggested throughout the day. If the answer to all of the questions is "no", then proceed to Part 2 (Exhibit 4-7) to check for permissive FYA operation by time of day.

Exhibit 4-6 Part 1: Protected-Only Left Turn Operation 24 Hours per Day

Part 1: Protected Only Operation - 24 hrs/day Guidelines		
Question 1: Conflicting Left Turns		
○ Yes ○ No	Do the opposing left turn paths conflict?	> If the answer is **Yes,** then use Protected Operation 24 hours/day. > If the answer is **No,** proceed to the next question.
Question 2: Limited Sight Distance		
○ Yes ○ No	Does the left turner have very limited sight distance as defined in the current AASHTO "A Policy on Geometric Designs of Highways and Streets"?	> If the answer is **Yes**, then use Protected Operation 24 hours/day. > If the answer is **No**, proceed to part 2 to check for FYA by TOD.
> If the Answer is **Yes** to Question 1 or 2, use Protected Operation 24 hours/day > If the Answer is **No** to all of the above, proceed to Part 2.		

Test for FYA Operation by Time of Day

Part 2 (Exhibit 4-7) should be performed for each time of day interval. Typically, the evaluation would be for 4 or more intervals throughout the day (AM Peak, Mid-day Peak, PM Peak and Off Peak). Other intervals can be evaluated as warranted.

For the Cross-Product (Question 6) use the highest hourly cross product during the interval evaluated.

If the answer to any of the questions in Part 2 are "yes", protected only operation is suggested. Use engineering judgment if a decision is made to operate permissive FYA for the evaluated time period.

Question 6 does include a threshold volume of 240 vph for the subject left turn. However, if the opposing through volume is low, apply engineering judgment to determine if FYA operation could be used even if the left turn volume exceeds 240 vph.

If permissive FYA operation is allowed, protected/permissive operation may be investigated. The decision to use protected/permissive operation should be based on a capacity analysis.

Exhibit 4-7 Part 2: Permissive FYA Operation by Time of Day

Part 2: Time of Day Operation of FYA _____ Start Time _____ End Time		
Question 3: Number of Left Turn Lanes		
◯ Yes ◯ No	Does the left turn have two (2) or more lanes?	> If the answer is **Yes,** Protected Operation is **suggested** during the **high** volume times of the day (use Engineering Judgment if Decision to run FYA by TOD). > If the answer is **No**, proceed to the next question.
Question 4: Number of Opposing Through Lanes		
◯ Yes ◯ No	Does the left turn face three (3) or more opposing through lanes?	> If the answer is **Yes,** Protected Operation is **suggested** during the **high** volume times of the day (use Engineering Judgment if Decision to run FYA by TOD). > If the answer is **No**, proceed to the next question.
Question 5: Crash History		
◯ Yes ◯ No	Is protected/permissive operation in place and is there a high number of left turn related crashes during this time interval over a 3-year period susceptible to correction by protected only phasing?	> If the answer is **Yes,** Protected Operation is **suggested** for this TOD. > If the answer is **No,** proceed to the next question.
Question 6: Speed and Cross Product		
◯ Yes ◯ No	Is the Speed 45 MPH or greater and the Peak Hour left turn volume greater than 240 vph or is the peak hour cross product greater than 80,000 (100,000 if 2 opposing lanes)?	> If the answer is **Yes,** Protected Operation is **suggested** for this TOD. > If the answer is **No,** FYA may be possible during this time period.
> If the answer is **Yes** to any Question, Protected Only Operation is **Suggested** during this TOD (use Engineering Judgment if Decision to run FYA by TOD). > If the answer is **No** to all Questions, FYA (permitted mode) may be used during this TOD.		

Definitions

- ✓ **Protected only left turn operation**: signal phasing that allows left turn movements to only be made on an exclusive phase (green arrow).
- ✓ **Conflicting Left Turn Paths**: At some locations geometric constraints at the intersection cause the paths of opposing left turn vehicles to cross as overlap creating a conflict. An example is an approach that crosses a divided roadway with a wide median. In these locations, it may be necessary to operate the left turns in a lead-lag sequence or a split phase sequence, not allowing simultaneous opposing left turns. This operation will require protected left turns.
- ✓ **Opposing through lane (conflict)**: The opposing through lanes are the lanes across from, and in conflict with, the left turning vehicle. Multiple lanes make it difficult for a driver to evaluate gaps in oncoming traffic. An opposing separate right turn lane will typically not be counted with opposing

through lanes unless engineering judgment indicates that the lane configuration and number of right turns will cause conflicts with the left turn movement.

- ✓ **Limited Sight Distance (Requirements)**: The minimum sight distance values necessary for the design vehicle volume to complete the turn movement. Distance should be calculated from the stop bar for the mainline left turning vehicle. Measurement is based on travel path, speed, and acceleration vehicle height. Both the sight distance for passenger vehicles and trucks should be checked using heights and distance requirements per the AASHTO Geometric Design Guide. The current reference at time this manual was prepared is the 2004 Guide, Chapter 9, Exhibit 9-67).
- ✓ **Dual Left Turn Lanes**: Multiple left turn lanes may consist of exclusive left turn lanes or a combination of exclusive left turn lanes and lanes that are shared by through and left turning traffic. Both the dual lane and the left turn lane opposing this operation are suggested to operate with protected phasing. Left turn lanes without opposing traffic, such as left turns off of a one- way street, does not require protected only phasing based upon this criteria. It might also be possible to run the FYA in permissive mode during low volume times of the day.
- ✓ **Protected/permissive left turn operation**: signal phasing that provides an exclusive phase (green arrow) followed by a permissive phase (flashing yellow arrow), time during the signal cycle where left turning traffic may make a left turn after yielding to oncoming traffic.
- ✓ **Left Turn Related Collisions**: These are Collisions that could be corrected by protected only phasing, such as those between those involving a left turning vehicle and an opposing through vehicle. At higher speeds the crash collisions are likely to be more severe. Therefore, a lower number of collisions might be used as the parameter for consideration for high-speed approaches. Because of the variations in collisions overtime, an average number of collisions per year over a 3- year period should be used if the data is available.
- ✓ **Speed**: Because it can be difficult for a driver to accurately judge available gaps in traffic approaching at high speeds, the engineer must exercise discretion when considering permissive or protected permissive left turn phasing with opposing speeds of 45 MPH or above.

  Use of posted speed limit is recommended. Non-arterial approaches may have lower speeds than the posted speed limit because they are often in a stop condition upon the arrival of traffic. Grades affect the acceleration rate of the left turner and the stopping distance and speed of the opposing through traffic and are therefore considered in conjunction with speeds.
- ✓ **Cross Product**: The left turn volume multiplied by the opposing through volume. The cross product values used are taken from the Wisconsin Department of Transportation (WisDOT) Traffic Signal Design Manual discussion on left turn conflicts analysis, Chapter 2, Section 3, Subject 4. Cross product used represents a high frequency of conflicts for left turners looking for gaps in through traffic.

FYA during Free Operation

With the variable-phasing operation of the FYA head, free operation will no longer have an assigned fixed phasing operation. Therefore, standard free operation will need to be set up in the signal controller so technicians can put signals quickly to FREE with a standard phasing operation desired at the specific time. Here is an example of the standard FREE operations that will need to be set up in the signal controller:

1. All left turns protected
2. All left turns protected/permissive
3. All left turns permissive
4. Mainline protected, cross street protected permissive
5. Mainline protected, cross street permissive
6. Mainline protected/permissive, cross street protected
7. Mainline protected/permissive, cross street permissive

8. Mainline permissive, cross street protected
9. Mainline permissive, cross street protected/permissive Minimum Green Times

Minimum Green Times

MnDOT currently sets the minimum green time based on the type of phasing operation where protected lefts have a 7 second minimum green and protected/permissive lefts have a 5 second minimum green. Given the FYA head is a variable phasing operation head, a decision will need to be made as to if there should be more than one minimum green value that changes with the phasing operation, or if a universal minimum green should apply to all phasing operations.

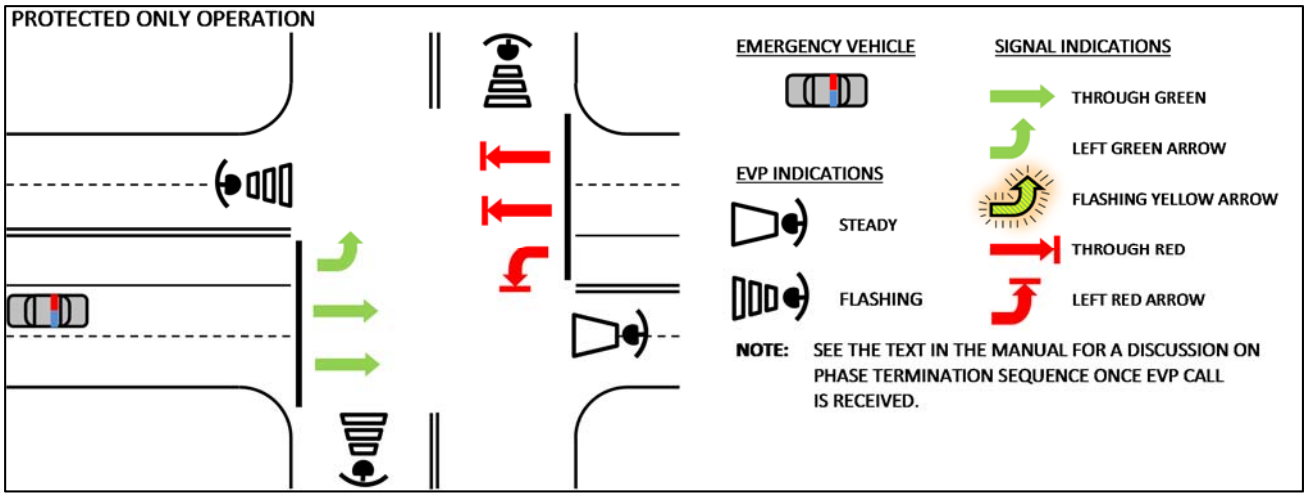
If one minimum green is used, and if a left turn phase will ever run protected, the left turn minimum green should be set at 7 seconds. If a left turn will never run protected (i.e. only run protected/permissive or permissive), then the left turn minimum green should be set at 5 seconds.

EVP Preemption Operation under FYA

A. Protected-only Operation

✓ When the FYA is not allowed (protected only), the pre-emption will bring up the protected left turn and the adjacent through phase. The opposing FYA will not be allowed during preemption (refer to Exhibit 4-8).

Exhibit 4-8 Emergency Vehicle Preemption: Protected-Only Operation



B. **Protected/Permissive Operation** (Note: Permissive operation is the same as protected/permissive operation for preemption as permissive operation is just a subset of protected/permissive operation.)

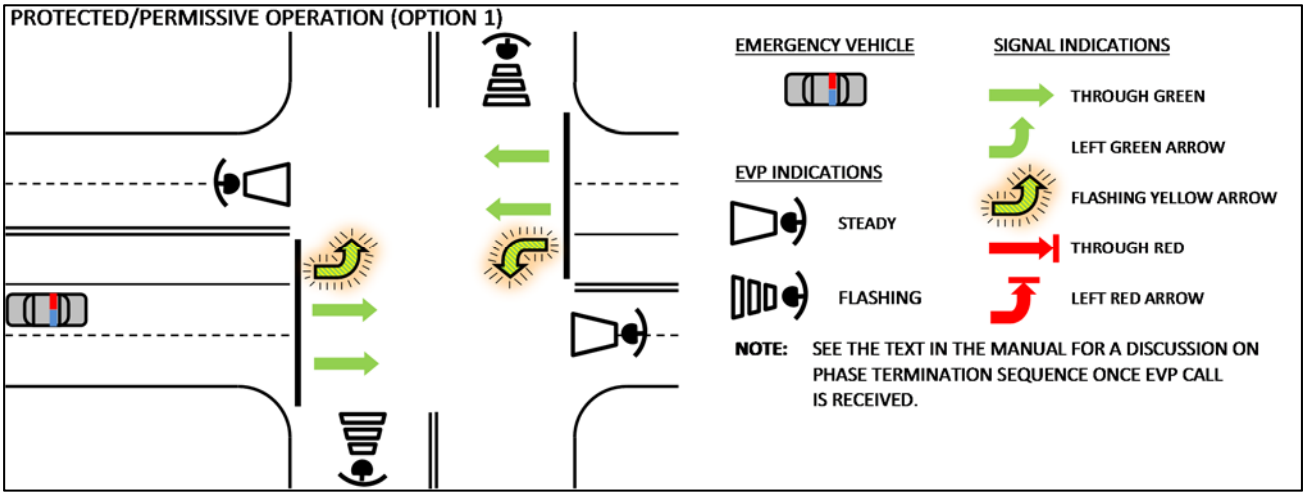
There are currently two options for running pre-emption under protected/permissive operation and the option is left up to emergency-vehicle preference based on their most common response routes.

The current two options for preemption for Protected/Permissive operation:

1. Don't Terminate Through Phases (preempt on through phases, FYA on, i.e. no protected left turn phases) - Refer to Exhibit 4-9.
   a) If the through phases in the direction of the emergency vehicle (EV) are green and lefts are in FYA, pre-empt keeps the throughs and FYAs on.
   b) If the through and left in the direction of the EV are green, terminate the left and bring up the opposing through and operate the lefts in FYA.

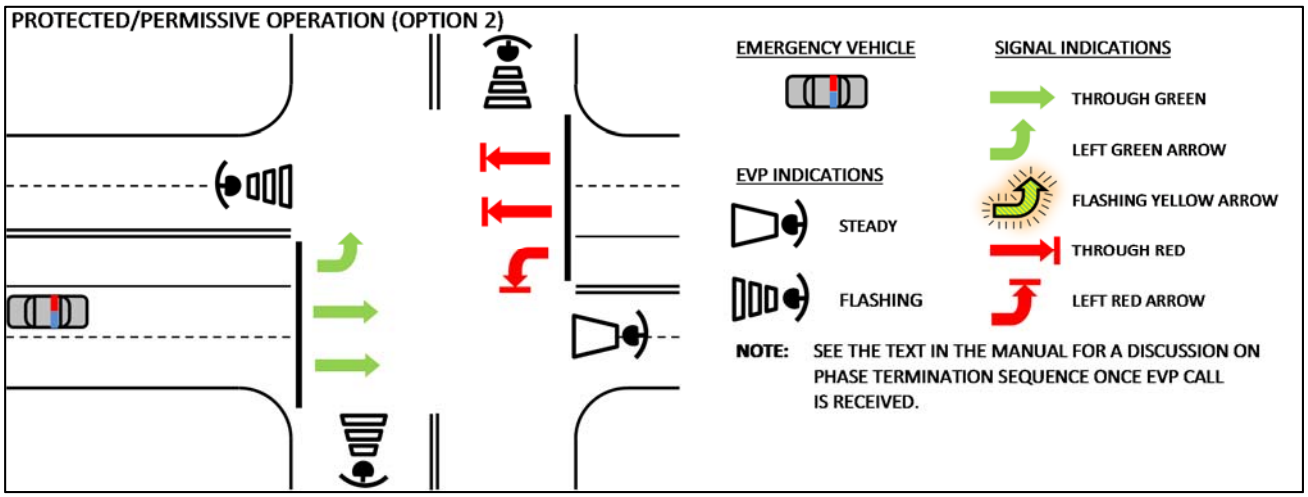
c) If the side street throughs are green, a preempt on the main street terminates the side street and brings up the main street throughs and FYAs.

Exhibit 4-9 Emergency Vehicle Preemption: Protected/Permissive Operation (Option 1)



2. Terminate Both Through Phases (FYA off) –Refer to Exhibit 4-10.
   a) If the through phases in the direction of the EV are green and lefts are in FYA, pre-empt terminates both through phases, and brings the through and left green arrow for the direction of the EV (FYA off for opposing left turn).
   b) If the left green arrow and through phase in the direction of the EV are green, pre-empt the left green arrow and through phase and then brings up this same green arrow and through phase (FYA off for opposing left turn).
   c) If the left green arrow and through phase in the opposing direction of the EV are green, pre-empt terminates the left green arrow and through phase and brings up the opposing (EV direction) left green arrow and through phase (FYA off for opposing left turn).
   d) If the side-street is green, a pre-empt on the main street terminates the side-street phases and bring up the left green arrow and through in the direction of the EV (FYA off for opposing left turn).

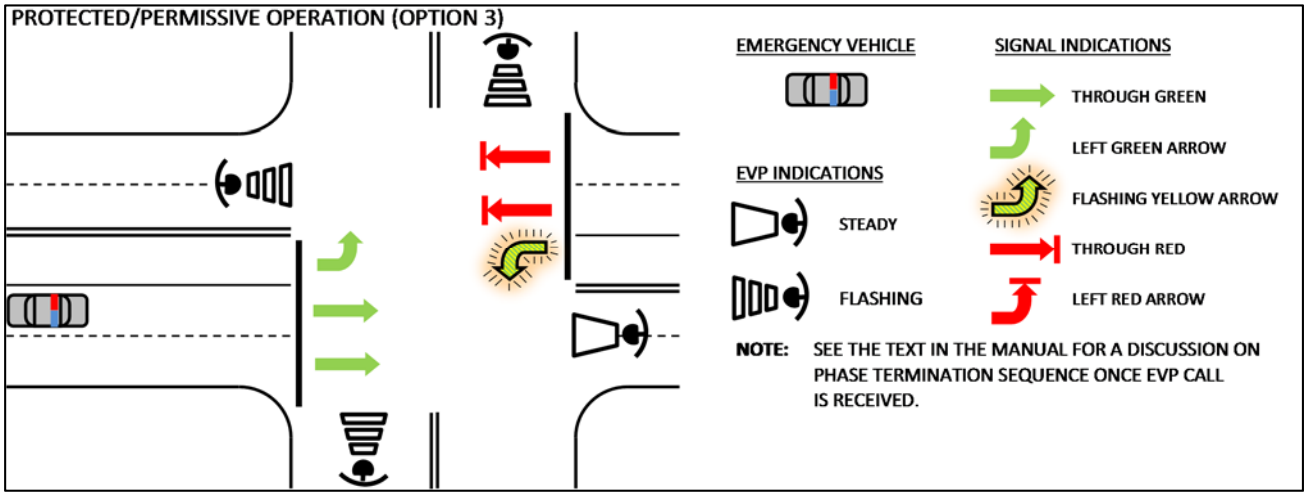
Exhibit 4-10 Emergency Vehicle Preemption: Protected/Permissive Operation (Option 2)



An additional Third Option with a FYA head while running lagging lefts during prot/permissive or permissive operation is discussed here – Refer to **Exhibit 4-11**.

3. Terminate One Through Phase (preempt for through and adjacent left, opposing FYA on)
   a) If the through phases in the direction of the EV are green and lefts are in FYA, pre-empt terminates opposing through phase, and brings up green arrow and through for the direction of the EV (FYA on for opposing left turn)
   b) If the left green arrow and through phase in the direction of the EV are green, pre-empt continues the left green arrow and through phase (FYA on for opposing left turn)
   c) If the left green arrow and through phase in the opposing direction of the EV are green, pre-empt terminates the left green arrow and through phase and brings up the opposing (EV direction) left green arrow and through phase. (FYA on for opposing left turn)
   d) If the side-street is green, a pre-empt on the main street terminates the side-street phases and bring up the left green arrow and through in the direction of the EV (FYA on for opposing left turn).

Exhibit 4-11 Emergency Vehicle Preemption: Protected/Permissive Operation (Option 3)



RR Preemption Operation

The FYA 4-section head should help railroad preemption operations given the flexibility to operate in either protected, protected/permissive, or permissive modes with no concern of a left-turn trap issue. It might be possible to run the left turn as a FYA UNLESS railroad preemption occurs (in which case it would run in protected only operation). This issue is currently under development and more information is forthcoming. See the MnDOT OTST website listed below for the most up-to-date information.

www.dot.state.mn.us/trafficeng/publ/index.html

4.11 Accessible Pedestrian Signal (APS) Operation

The MN MUTCD Section 4A.2 defines an Accessible Pedestrian Signal as "a device that communicates information about pedestrian timing in nonvisual format such as audible tones, verbal messages, and/or vibrating surfaces." The APS provides information to the pedestrian about:

- ✓ The existence and location of the pushbutton
- ✓ The beginning of the walk interval
- ✓ The direction of the crosswalk
- ✓ Intersection street names

MnDOT has formed an APS committee in order to standardize APS operation for consistency across the state. This committee was established after discussion with the North Central Institute of Transportation Engineering (NCITE) Intersection Traffic Control Committee stating that MnDOT felt it was important to establish APS operating standards that would be utilized by agencies across Minnesota to create consistency for users. The intent is to meet with local agencies and develop a standard to be used by all agencies.

Currently, there are two APS buttons on the MnDOT Approved Products list (Polara Engineering, distributed by Brown Traffic and Campbell Company, distributed by Traffic Control Corp.). One issue with making recommended operational practices is that one product may offer a feature that another manufacturer does not. The intent of the APS committee is not to require an operation that one of the products on the APL currently does not offer. This will require shop testing to assure that the committee does not make operational recommendations that one product can't currently provide.

The current operational practice standards per MN MUTCD and FHWA guidance:

- ✓ Speech messages will be used during the walk indication when the pedestrian buttons are less than 10' apart. If more than 10' apart, the audible walk indication shall be a percussive tone.
- ✓ Speech walk messages and the percussive tone walk indication can be used on different buttons at the same intersection during the walk interval.
- ✓ An audible countdown during the ped clearance interval will not be used. Per the MN MUTCD. "Following the audible walk indication, accessible pedestrian signals shall revert to the pushbutton locator tone during the pedestrian change interval."
- ✓ Length of "extended push" time to activate function shall be 2 seconds

Additional details on the work of this committee and operational recommendations will be published on the OTST website. Refer to the website for future details (www.dot.state.mn.us/trafficeng/).

4.12 Guidelines for the Inspection and Operation of Railroad Preemption at Signalized Intersections

Introduction

This section provides guidelines and recommendations for the installation, operation and inspection of traffic signals that are preempted either by trains or by Light Rail Transit (LRT) vehicles utilizing preemption. Yearly inspections will be performed and submitted to the Office of Freight, Railroads & Waterways.

Scope

The guidelines and procedures contained in this section apply to MnDOT, and to county and city agencies through the state aid process. MnDOT district offices may assist local agencies in performing inspections, if requested.

The responsibility for the operation of the highway/railroad preempted traffic signals remains with the district, county or city having operational jurisdiction. Neither an inspection nor these guidelines substitute for sound engineering judgment in the operation of traffic signals.

These are general guidelines and should be used only as a guide. Other factors at each location must be considered in applying these guidelines. The Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD), Traffic Control Devices Handbook, Railroad-Highway Grade Crossing Handbook (FHWA-TS-86-215), and the Institute of Transportation Engineers' Preemption of Traffic Signals at or Near Railroad Grade Crossings with Active Warning Devices should be referred to for additional guidance.

Guidelines for Preemption

If either of the following conditions are present, consideration should be given to interconnect the traffic signal and railroad grade crossing:

A. Highway traffic queues that have the potential for extending across a nearby rail crossing.

B. Traffic queued from a downstream railroad grade crossing that have the potential to interfere with an upstream signalized intersection.

The 1991 version of the Minnesota Manual on Uniform Traffic Control Devices, specifies that the recommended distance between traffic signal and grade crossing for interconnection is 200 feet (65 meters). Recent research has found this distance to be inadequate. The following formulas provide a method for estimating the queue length that can be expected on the approach. If the queue length exceeds the storage between the intersection stop bar and 6 feet (2 meters) from the nearest rail, the railroad signal and the traffic signal should be interconnected.

A method for estimating queue length (with about 95 percent certainty) is as follows:

$$L=2qrv(1+p)$$

Where: L = length of queue, in feet or meters per lane;

q = flow rate, average vehicles per lane per second;

r = effective red time (time which the approach is red or yellow per cycle);

v = passenger vehicle length, assume 25 feet or 7.5 meters;

p = proportion of trucks;

The 2 is a random arrival factor.

This formula provides a good estimate of queue lengths, where the volume to capacity (v/c) ratio for the track approach is less than 0.90. However, for v/c ratios greater than 0.90, some overflow queues could occur as a result of fluctuations in arrival rates. To compensate for this condition, it is suggested that one vehicle should be added for each percent increase in the v/c ratio over 0.90. Accordingly, in cases where the v/c ratio ranges from 0.90 to 1.00, the following formula applies:

$$L=(2qr+\Delta x)(l+p)v$$

Where $\Delta x = l00(v/c\ ratio - 0.90)$. Thus, for a *v/c* ratio 0.95, Δx would be 5 vehicles in the above formula. This formula cannot be used if the *v/c* ratio 1.0, then a field queue study will be needed in that case.

Queue lengths for through traffic and for left turns should both be checked to determine which queue is the most critical.

Guidelines for Design

When the determination has been made to preempt the traffic signal for a train, many items need to be considered. Some are listed here: distance between the traffic signal and the grade crossing, intersection geometry, track orientation, approach speed of train, train frequency, volume of vehicular traffic, vehicle type, pedestrian, and equipment at the intersection and grade crossing.

Short distances: Where the clear storage distance between the tracks and the highway intersection stop line is not sufficient to safely store a design vehicle like the longest, legal truck combination, or if vehicles regularly queue across the tracks, a pre-signal should be considered. An engineering study should be performed to support this recommendation. A pre-signal may also be beneficial if gates are not provided. This supplemental traffic signal should be carefully designed to avoid trapping vehicles on the tracks. Visibility-limited traffic signals at the intersection may be needed to avoid driver conflict and confusion. The DO NOT STOP ON TRACKS sign (R8-8) and STOP HERE ON RED sign (R10-6) of the MN MUTCD should also be used. Certain situations where gates are not present may also require prohibiting turns on red.

Guidelines for Operation

The MN MUTCD (Section 8C-6) requires that “The preemption sequence initiated when the train first enters the approach circuit, shall at once bring into effect a highway signal display which will permit traffic to clear the tracks before the train reaches the crossing. The preemption shall not cause any short vehicular clearances and all necessary vehicular clearances shall be provided. However, because of the relative hazards involved, pedestrian clearances may be abbreviated in order to provide the track clearance display as early as possible. After the track clearance phase, the highway intersection traffic control signals should be operated to permit vehicle movements that do not cross the tracks, but shall not provide a through circular green or arrow indication for movements over the tracks”.

If the traffic signal is equipped with emergency vehicle preemption, the confirmation lights shall flash for all approaches during the preempt sequence.

Guidelines for Inspection

Existing highway/railroad preempted traffic signals shall be inspected on an annual basis. It is the responsibility of the roadway authority that has responsibility for the operation of the traffic signal to initiate the annual inspection. A copy of the completed inspection forms shall be forwarded to the Office of Freight, Railroads & Waterways on an annual basis.

The District Traffic Engineer will ensure that each location under MnDOT jurisdiction is inspected. Through the State Aid program, cities and counties are required to perform annual inspections.

The rail authority shall be contacted prior to inspection and a representative shall be present during each inspection. This joint inspection is critical, as the operation of railroad preemption systems is dependent on both the railroad and highway agencies.

The inspection should be done while a train passes through the area if possible.

During this inspection, a general review of the highway intersection and railroad crossing for proper signing, pavement markings, signals, sight distances, and changes in conditions should be made.

It is also advised that all traffic signals without railroad preemption need to be reviewed when traffic patterns change, see if additional traffic control/RR preemption is needed.

Annual Inspection Form

The following information is a printout of the **Railroad Preemption Timing and Annual Inspection Form** (xls). This information is available from the MnDOT website:

www.dot.state.mn.us/trafficeng/signals/signalworksheets.html

HANDOUT

Mn/DOT ANNUAL TRAFFIC SIGNAL AND RAILROAD PREEMPTION INSPECTION FORM

1. LOCATION DATA

CITY:	COUNTY:	OPERATING AGENCY:
HIGHWAY INTERSECTION:		Mn/DOT DISTRICT:
RAILROAD COMPANY:	RAILROAD INVENTORY NUMBER:	

2. RAILROAD PREEMPTION PHASING SEQUENCE

CRITICAL PHASES		TRACK CLEARANCE PHASE(S)	PREEMPT HOLD OR CYCLE PHASES
Vehicle:	**Pedestrian:**		

3. RAILROAD DATA

RR ACTIVE WARNING DEVICES: **Flashers, no gates.**	GATE-DOWN LOGIC INSTALLED?
DETECTOR MODEL/TYPE:	
MAXIMUM TRAIN SPEED (MPH):	NUMBER OF TRACKS:
NUMBER OF TRAINS PER DAY (and any helpful additional information):	
DATE OF MOST CURRENT RAILROAD PLANS (in bungalow):	
APPROACH AND ISLAND LENGTHS (FEET): Island: Approaches:	

4. TRAFFIC SIGNAL HARDWARE DATA

CONTROLLER MODEL:	OPERATION (pretimed/actuated):
EVP PRESENT?	CONFIRMATION LIGHTS PRESENT?
ROADWAY CHANGES?	
WORKING MANUAL PREEMPTION SWITCH IN CABINET?	
LOOPS UPSTREAM OF TRACKS (if vehicles must stop before tracks)?	
TYPE OF BACKUP POWER:	

5. RAILROAD EQUIPMENT PROGRAMMED TIMINGS

Equipment Response (Buffer) Time:		**sec.**
Extra Warning Time (overspeed tolerance, wide/angled crossings):		**sec.**
Minimum Warning Time:	**20**	**sec.**
Advance Preemption Time:		**sec.**
Total Warning Time (excludes equipment response/buffer time):	**20**	**sec.**

6. NOTES

7. FIELD TESTING AND INSPECTION

Weather Conditions:

Test #	1	2	3	4
Train's Direction of Travel				
	Cumulative Time (sec)			
Preempt call received at				
Railroad flasher activated at				
Gate descent started at	no gates	no gates	no gates	no gates
Gate descent completed at	no gates	no gates	no gates	no gates
End of track clearance green (start of track clearance yellow) at				
Train arrived at				
Measured Total Warning Time:				
Railroad equipment and lamps functioned:				
Track clearance and preempt hold/cycle phases operated as expected:				

8. REVIEW TEAM (INCLUDING TELEPHONE NUMBERS)

MAXIMUM WARNING TIME NEEDED BY TRAFFIC SIGNAL: **23.2 sec**

DOES MEASURED WARNING TIME MEET OR EXCEED MAXIMUM WARNING TIME NEEDED BY TRAFFIC SIGNAL?

HIGHWAY		INSPECTION DATE:
RAILROAD		

HANDOUT
HANDOUT
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HANDOUT

9. OTHER INFORMATION/NOTES

4.14 Guidelines for Consideration and Timing of Advanced Warning Flashers

The following guidelines indicate when the installation of AWF for signal change interval may be considered. Due to the complex nature of traffic flow characteristics, these guidelines should be applied along with engineering judgment. Guidelines should be reviewed for each prospective installation.

AWF should only be installed in response to a specifically correctable problem, not in anticipation of a future problem. Generally, AWF implementation is appropriate only at high speed locations. Before an AWF is installed, other remedial action should be considered.

The following guidelines generally apply only where posted speed is 55 mph or higher.

CATEGORY	CRITERIA	COMMENT
1. Isolated or Unexpected signalized intersection	Where there is a long distance from the last intersection at which the mainline is controlled, or the intersection is otherwise unexpected.	This guideline may be applicable where the distance from the last intersection is greater than 10 miles, or at a freeway terminus, or at other locations where the intersection is unexpected.
2. Limited sight distance	Where the distance to the stop bar, D, with two signal heads visible is insufficient: $D \leq 1.467vt + \frac{v^2}{0.93(a + 32.2s)}$ Where: D = distance to stop bar feet v = posted speed in mph t = reaction time, 2.5 seconds a = deceleration rate 8 ft/s^2 (trucks) 10 ft/s^2 (all traffic) s = decimal gradient	See Graphs of Limited Sight Distance, Exhibit 4-12 & Exhibit 4-13. A sight distance falling below the lines for the given speed and grade indicates the possible need for AWF.

CATEGORY	CRITERIA	COMMENT
3. Dilemma Zone	Where a dilemma zone exists for all traffic or for heavy vehicles. A dilemma zone exists if: $$Y \leq t + \frac{1.467v}{2(a + 32.2s)}$$ Where: Y = yellow interval in seconds v = Posted speed in mph t = 1 second a = deceleration rate 8 ft/s^2 (trucks) 10 ft/s^2 (all traffic) s = decimal gradient	See Graphs on Minimum Yellow Intervals, Exhibit 4-14 & Exhibit 4-15. If the yellow interval is less than indicated, AWF may be considered (longer yellow should be considered first).
4. Crashes	If an approach has an crash problem, the intersection should be examined for existence of dilemma zone or sight distance restriction.	If no sight distance or dilemma zone problems exist, AWF may not be an appropriate countermeasure to crash problems.
5. Heavy Truck Volume	Where the roadway has a grade of 3% or greater and truck volume exceeds 15%.	
6. Engineering Judgment		

Combinations of above guidelines or other considerations may justify the installation of AWF.

Engineering judgment should be based on additional data such as complaints, violations, conformity of practice, and traffic conflicts. Prior to installing AWF, consideration should be given to other countermeasures including but not limited to: adjustment of timing parameters which may include increasing yellow and/or all red intervals, improving detection, or modification of the signal system as by adding signal heads, adjusting speed limits.

Guidelines for Installation

1. **Advanced Warning Flasher** - The Advanced Warning Flasher design details are shown on the web: www.dot.state.mn.us/trafficeng/signals/signaldetails.html. The flasher shall flash yellow in a (inside-outside) wig-wag manner prior to the termination of the green (See number 3, below), and during the yellow and red periods of the signal. The flasher will also flash if the signal goes into flashing operation. Power shall be supplied to the AWF from the signal control cabinet.

2. **Advanced Warning Flasher Sign Placement** - The AWF should be set back from the intersection in accordance with the table shown below. At locations on four lane divided roadway, the AWF shall be placed on both sides of the approach.

Posted Speeds (mph)	AWF Placement	Leading Flash (seconds)
40	560 ft	8.0
45	560 ft	7.0
50	700 ft	8.0
55	700 ft	7.0
60	850 ft	8.0
65	850 ft	7.5

3. **Leading Flash** - The Leading Flash is the amount of time, prior to the signal turning yellow, that the AWF flashes. The AWF shall flash during the Leading Flash Period and continue flashing through the signal's yellow clearance interval and the red. The Leading Flash time is shown in the table above.

For existing systems where the placement is other than what is listed in the table above, the Leading Flash Time can be computed by the following formula:

Where:

F = Leading Flash Time, seconds

D = AWF Placement, meters

v = posted speeds, mph

$$F = \frac{0.68D}{v} - 1.5$$

4. **Detector Placement** - The detection of the intersection shall be determined without regard to the AWF.

Exhibit 4-12 AWF Limited Sight Distance (> 15% Trucks)

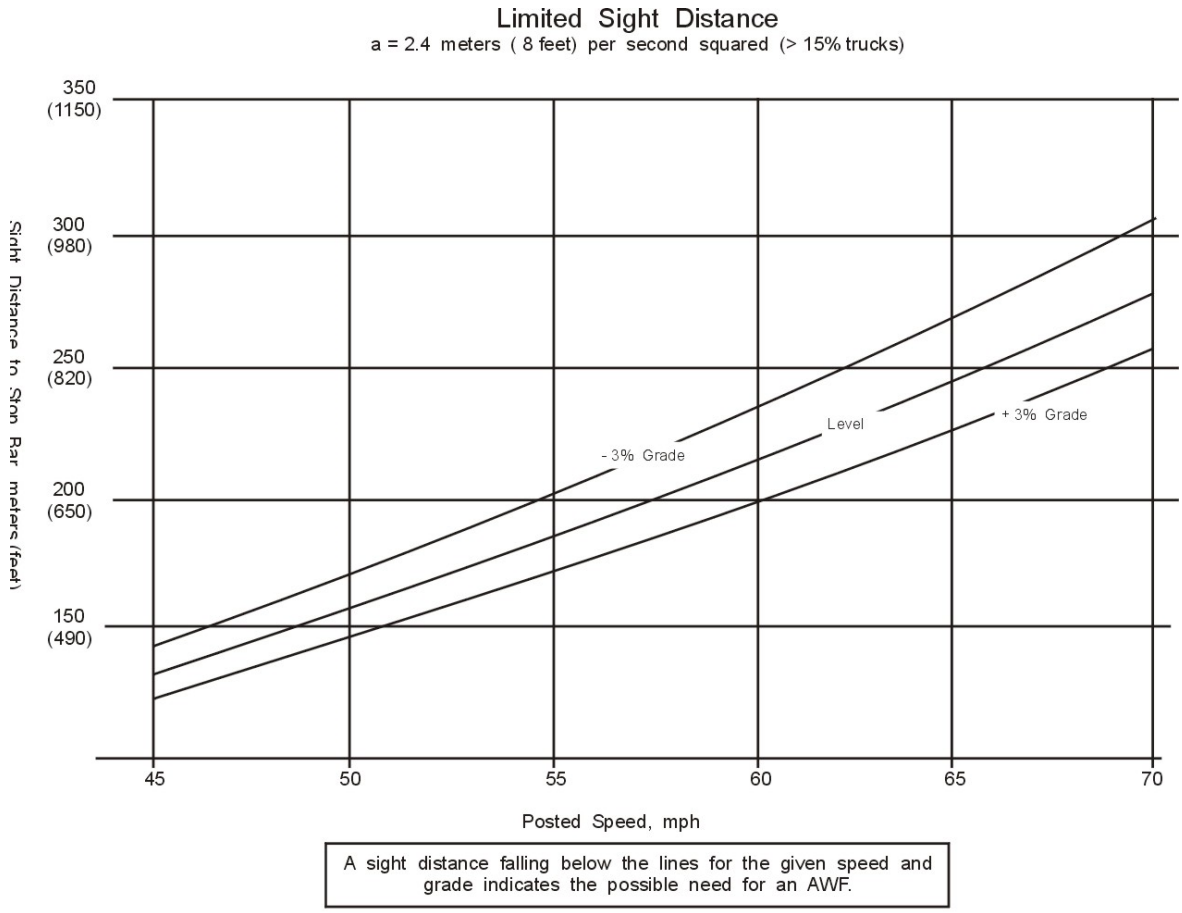
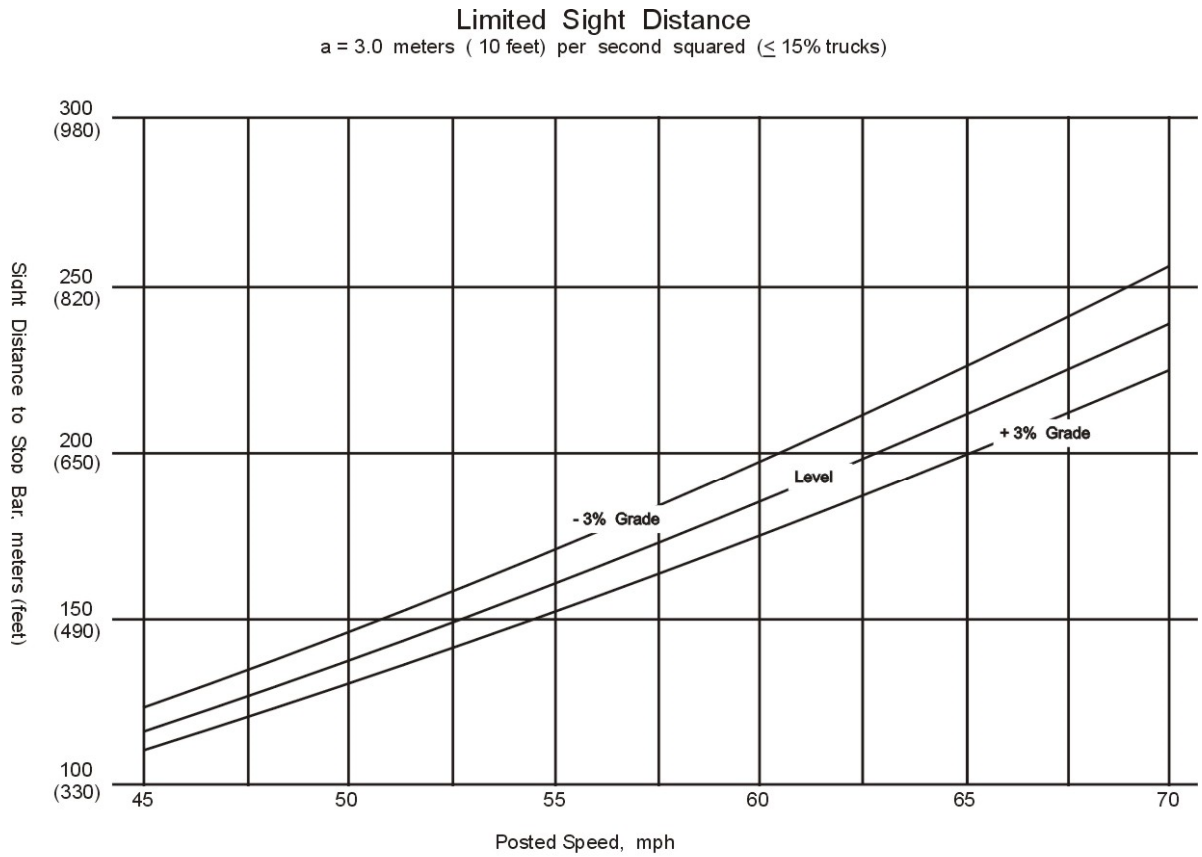


Exhibit 4-13 AWF Limited Sight Distance (≤ 15% Trucks)



A sight distance falling below the lines for the given speed and grade indicates the possible need for an AWF.

Exhibit 4-14 AWF Recommended Yellow Intervals (> 15% Trucks)

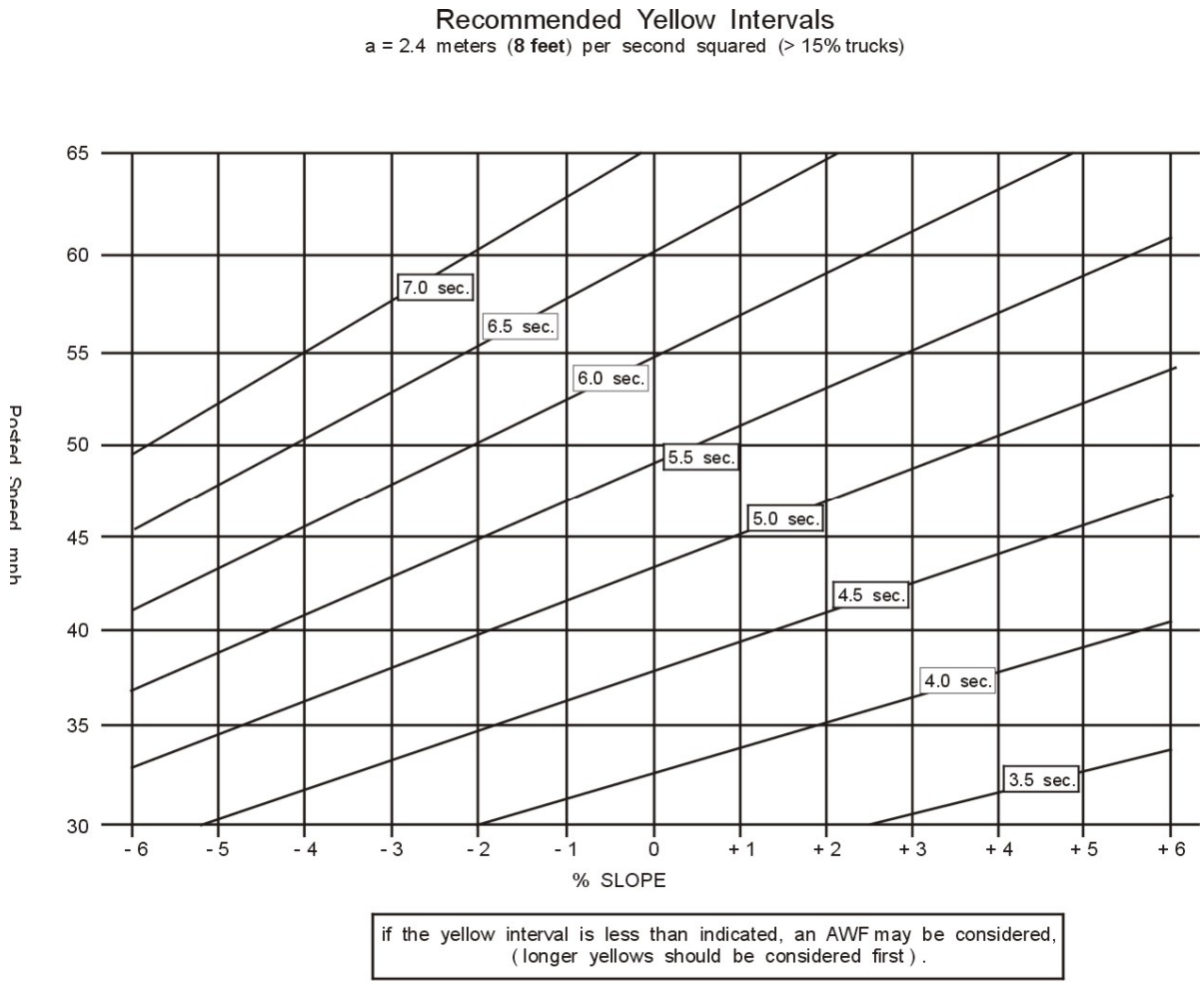
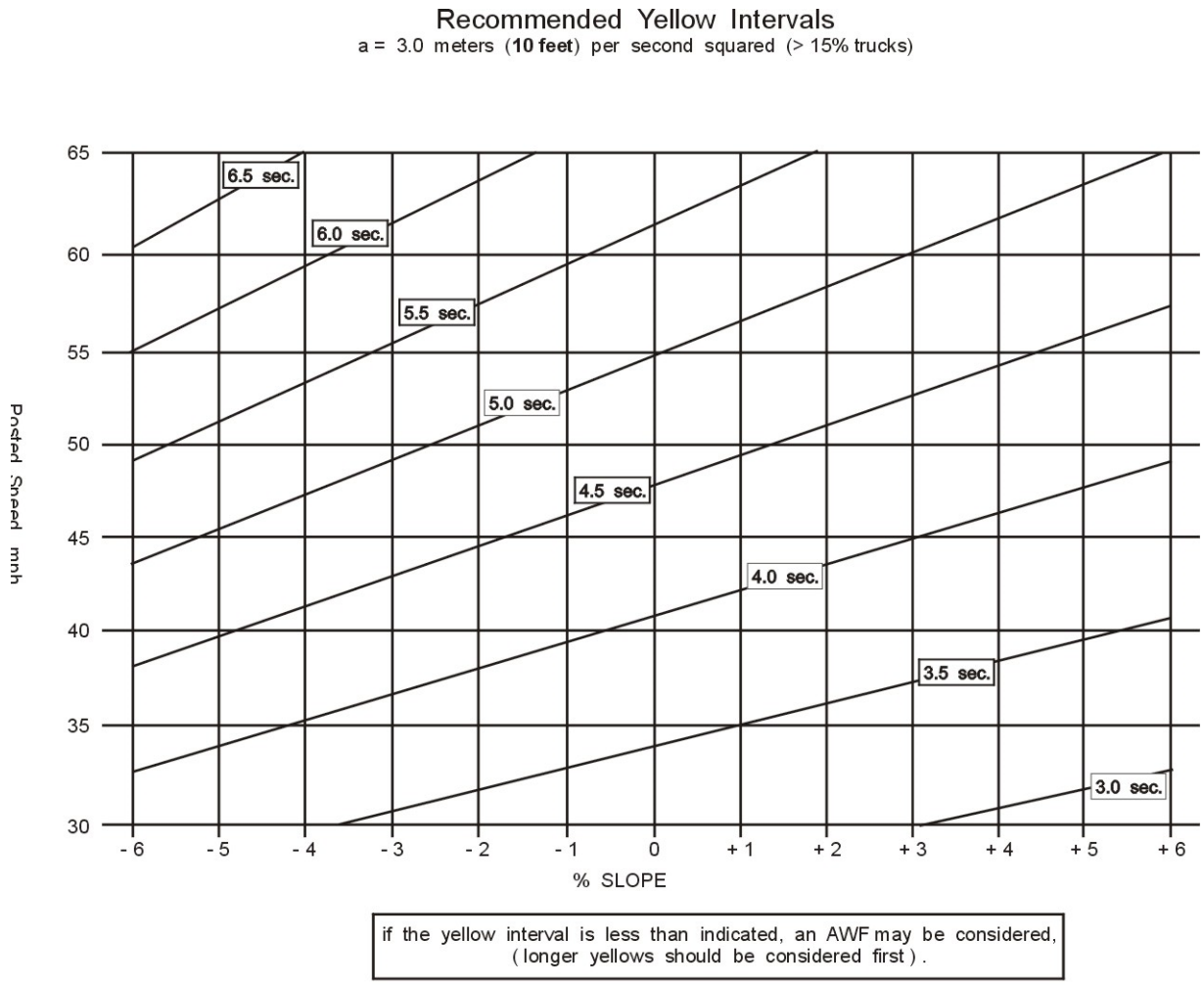


Exhibit 4-15 AWF Recommended Yellow Intervals (≤ 15% Trucks)



See **MN MUTCD** for the Installation and Operation of Advanced Warning Flashers.

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5 COORDINATION CONCEPTS

5.1 Cycle Length

The cycle length is the total time to complete one sequence of signalization around an intersection. In an actuated controller unit, a complete cycle is dependent on the presence of calls on all phases. In a pre-timed controller unit (see page 3-5) it is a complete sequence of signal indications.

The equation presented on page 3-1 is for isolated pre-timed signal locations only. A detailed network analysis should be performed using a software package such as Synchro or TRANSYT for cycle length determination in a coordinated system. The use of computer models allows for multiple iterations of varying cycle combinations to determine the optimum signal timing parameters.

5.2 Signal Timing Intervals and Splits

The sum of the green, yellow, and all red intervals typically defines an individual phase **split**. A split is then the segment of the cycle length allocated to each phase that may occur (expressed in percent or seconds).

The primary considerations that must be given to vehicle split times are as follows:

- ✓ The phase duration must be no shorter than some absolute **minimum time**, such as five to seven seconds of green plus the required clearance interval. If pedestrians may be crossing with this phase, their crossing time must also be considered and included in the minimum phase length.
- ✓ A phase must be long enough to avoid over saturating any approach associated with it. Too short a time will cause frequent **cycle failures** where some traffic fails to clear during its phase.
- ✓ A phase length must not be so long that green time is wasted and vehicles on other approaches are delayed needlessly.
- ✓ Phase lengths should be properly designed to efficiently balance the cycle time available among the several phases, not just “equitably” between, say, north-south and east-west.

5.3 Offset

The **offset** is the time relationship, expressed in seconds or percent of cycle length, determined by the difference between a fixed point in the cycle length and a system reference point.

Proper determination and application of intersection offsets provide for the efficient movement of platoons through multiple intersections during the green indication. Properly timed offsets can significantly reduce delay and improve driver satisfaction with the system timing.

5.4 Progression Measures

All of the coordinated system analysis models have some MOEs associated with the green bands in the Time-Space Diagram (TSD). In fact some of the models utilize progression MOEs as a component of the optimization objective function. The more common of these MOEs are introduced below.

Bandwidth Efficiency

PASSER II uses this measure as its objective function. This is simply the proportion of the cycle that is included in through green bands, extending the entire length of the system. A simple TSD showing perfect time-space progression illustrates the concept. Mathematically, efficiency is calculated as:

$$E = \frac{B_f + B_r}{2C}$$

where,

E = bandwidth efficiency,

B_f, B_r = bandwidths in the forward (f) and reverse (r) directions with respect to the arterial orientation, and

C = cycle length.

***Example**:* Bandwidth Efficiency

Number of Signalized Intersections = 5

Bandwidth (forward) = 40 seconds

Bandwidth (reverse) = 40 seconds

Cycle Length = 90 seconds

Then,

$E = (B_f + B_r) / 2C$

$= (40 \text{ sec} + 40 \text{ sec}) / (2 \times 90 \text{ sec})$

$= 0.44$ or 44%

Bandwidth Attainability

The attainability is the ratio of the total bandwidths to critical phase lengths for each of the directions on the arterial. Attainability is a measure of how much of the maximum available green is used for through progression, and is computed as:

$$A = \frac{B_f + B_r}{G_f + G_r}$$

where,

A = attainability

G_f, G_r = the critical (or minimum) green periods (including change periods) in the two directions, and

C = cycle length as before

***Example**:* Bandwidth Attainability

Number of Signalized Intersections = 5

Bandwidth (forward) = 40 seconds

Bandwidth (reverse) = 40 seconds

Cycle Length = 90 seconds

Intersection 1 $G_f = G_r = 60$ seconds

Intersection 2 $G_f = G_r = 55$ seconds

Intersection 3 $G_f = G_r = 55$ seconds

Intersection 4 $G_f = G_r = 45$ seconds

Intersection 5 $G_f = G_r = 50$ seconds

Then,

$A = (B_f + B_r) / (G_f + G_r)$

$= (40 \text{ sec} + 40 \text{ sec}) / (45 \text{ sec} + 45 \text{ sec})$

$= 0.89$ or 89%

This MOE is only reported by PASSER II. You can easily see that if attainability on a two-way street is less than 0.5, you can almost certainly improve the overall progression, including efficiency, by providing "perfect" one-way progression in the peak direction. PASSER II will not do this automatically, but you can instruct it to.

5.5 System Measures

Several other MOEs of interest are produced by most traffic operations models.

Total Travel

This value will be constant for any given network and demand distribution. This is simply the agreement of the product of link volumes and link lengths:

$TT_i = v_i L_i$

where,

TT_i = total travel on link i in veh-mi (veh-km) per hour;

v_i = traffic volume on link i, vph; and

L_i = length of link i in miles (km).

This MOE will not change in any given optimization, since the basic values (flow rates and link lengths) do not change.

Total Travel Time

Similar to the total travel, this system MOE is the product of link volumes and total time spent on the links, including delay or:

$TTT_i = v_i (L_i/V_i + d_i)$

where,

TTT_i = total travel time in veh-hr per hour on link i;

v_i = traffic volume on link i in vph;

V_i = average cruise speed on link i in mph (km/hr);

L_i = length of link i in miles (km);

d_i = total delay on link i in veh-hr per hour.

This measure should obviously decrease as the network signal timing is improved to reduce delay.

Average System Speed

The average speed in the system is an indication of the overall quality of flow in the network. It is simply the ratio of total travel (TT) to total travel time (TTT), and is thus expressed as veh-mi/veh-hr = mph (or similarly, km/hr). Links with zero distance (e.g. external links) or links that have been assigned zero delay and stop weights (e.g. non-vehicular links) should be excluded from the calculation of network average speed, as they are in TRANSYT-7F.

5.6 Computer Timing Tools

Computer models for developing optimized traffic signal timing plans have been available for over 25 years. The earliest versions of these programs were originally developed for mainframe computers and were often difficult to use. Over the years, these programs have evolved to take advantage of advances in microcomputer technology. In addition, the models themselves have been improved to better simulate the flow of traffic and make them more compatible with modern traffic control equipment. Of course, computer models cannot replace good engineering practice including field observation and hardware understanding.

Today there are more than 30 models that users can choose from for signal timing and analysis applications. A brief description of five widely utilized programs is provided below.

Synchro/SimTraffic. Synchro is a complete software package for modeling and optimizing traffic signal timings. The key features of Synchro include:

- ✓ ***Capacity Analysis***. Synchro provides a complete implementation of the 2000 Highway Capacity Manual, Chapter 16.
- ✓ ***Coordination***: Synchro allows you to quickly generate optimum timing plans.
- ✓ ***Actuated Signals****:* Synchro is the only interactive software package to model actuated signals. Synchro can model skipping and gap-out behavior and apply this information to delay modeling.
- ✓ ***Time-Space Diagram****:* Synchro has colorful, informative Time-Space Diagrams. Splits and offsets can be changed directly on the diagram.
- ✓ ***Integration with SimTraffic, CORSIM, and HCS****:* Synchro features preprocessor to these software analysis packages. Enter data once with easy-to-use Synchro, and then perform analyses with these software packages.

Synchro is a macroscopic traffic software program that replicates the signalized intersection capacity analysis as specified in the 2000 Highway Capacity Manual (HCM). Macroscopic level models represent traffic in terms of aggregate measures for each movement at the intersections. Equations are used to determine measures of effectiveness such as delay and queue length. These models do not account for "bottleneck" situations where upstream traffic deficiencies reduce the amount of traffic reaching downstream intersections. This would be a situation where Synchro may show a delay that is worse than SimTraffic since all of the volume is not reaching the intersection in SimTraffic.

A unique analysis methodology to Synchro is the “Percentile Method”. To account for variations in traffic, Synchro models traffic flow under five percentile scenarios, the 90th, 70th, 50th, 30th, and 10th percentile scenarios based on a Poisson distribution. If 100 cycles are observed, the 90th percentile cycle will represent the 10 busiest cycles. Each of these scenarios will represent 20% of the cycles actually occurring. This feature is discussed in more detail in Chapter 6.

When it comes to SimTraffic, this is a microscopic simulation model. SimTraffic has the capability to simulate a wide variety of traffic controls, including a network with traffic signals operating on different cycle lengths or operating under fully-actuated conditions. Most other traffic analysis software packages do not allow for a direct evaluation of traffic conditions operating under varying cycle lengths and traffic control.

Each vehicle in the traffic system is individually tracked through the model and comprehensive operational measures of effectiveness are collected on every vehicle during each 0.1-second of the simulation. Driver behavior characteristics (ranging from passive to aggressive) are assigned to each vehicle by the model, affecting the vehicle's free-flow speed, queue discharge headways, and other behavioral attributes. The variation of each vehicle's behavior is simulated in a manner reflecting real-world operations.

Since SimTraffic is a microscopic model, the full impact of queuing and blocking would be measured by the model. This is a situation where SimTraffic could show more delay when compared to Synchro.

The intention is to use Synchro and SimTraffic as companion models. Use Synchro to determine macro level LOS and delays (similar to the 2000 HCM), and use SimTraffic to simulate and animate to determine the 'problems' that may not be fully realized with a macro-level model.

Within Windows, Synchro is capable of drawing street layouts and networks onto a map background which can be imported as a DXF file, JPG image, or BMP image which can result in powerful animation graphics for public viewing. Synchro also serves as a preprocessor to the CORSIM, and the HCS programs. This means that users are required to enter input data just once for subsequent analysis is multiple software packages. Synchro can also illustrate time-space diagrams. Chapter 6 of this manual contains detailed information about Synchro 6.

TRANSYT-7F. TRANSYT-7F (Traffic Network Study Tool) is a macroscopic traffic signal model originally developed in the United Kingdom by the Transportation and Road Research Laboratory and later modified by the University of Florida Transportation Research Center for the Federal Highway Administration (FHWA). The basic premise of the analysis procedures used in TRANSYT-7F is the macroscopic, step-wise modeling of platoon progression and dispersion as it travels through a series of adjacent intersections. The TRANSYT-7F software has been designed to serve two primary functions. The first of these is the simulation of traffic as it flows through an arterial or network. The second is the development of optimized traffic signal timing plans. In both cases, it is required that all signals operate with consistent cycle lengths, though double cycling can be incorporated.

When using TRANSYT-7F to simulate traffic operations, input data requirements are similar to those required for the analysis detailed in the HCM methodology. User inputs include volumes and turning percentages, cycle and phase durations, and roadway geometries. Unlike the HCM analysis methods, saturation flow rates for various lane groups must also be input by the user, rather than intrinsically calculated within the model. Therefore, it is essential that an accurate estimate of saturation flow rates be obtained, through either field measurements or some other analytical means.

When using TRANSYT-7F for system optimization, much of the input data requirements are the same as those discussed above. Specifically, TRANSYT-7F requires that the user input phase sequences and minimum splits. It has the ability to optimize other signal settings, such as cycle length, phase lengths, and offsets. These values are optimized through either minimization or maximization of a user selected objective function, or performance index (PI). Options for this PI include minimization of a disutility index (DI) which is a linear combination of delays, stops, fuel consumption, and, optionally, excessive queuing; minimization of excess operating cost; or optimization of “forward progression opportunities”, which may also be done in combination with the disutility function.

Output reports produced by TRANSYT-7F, like the HCM, indicate both degree of saturation and delay for each lane group. TRANSYT-7F delay, like delay calculated with the HCM methodology, is a combination of uniform delay and random plus saturation delay. To calculate uniform delay, TRANSYT-7F simulates traffic flow, step by step throughout the cycle, to develop queue lengths. TRANSYT-7F then uses an algorithm to estimate uniform delay from these simulated queue lengths. When conducting the simulation, TRANSYT-7F accounts for the arrival pattern, due to upstream intersections and platoon dispersion, as well as lane group

start-up lost time and extension of effective green. Thus, unlike the HCM methodology, TRANSYT-7F calculates uniform delay based on simulation of the traffic flow. Therefore, no delay factor is necessary to account for the impacts of progression, since it is intrinsic in the flow profiles.

The second portion of delay, random plus saturation delay, is computed using the same algorithm found in the HCM for d_2. The delay calculated by TRANSYT-7F is total delay, rather than stopped delay. To equate TRANSYT-7F delay to HCM level of service, HCM level of service thresholds should be increased by a factor of 1.3.

Where the HCM methodology computes these measures of effectiveness based on a peak 15 minute flow period, TRANSYT-7F simulates only one cycle. Therefore, the MOEs should be viewed as an average for the analysis period. Thus, TRANSYT-7F, like the HCM methodology cannot account for effects of queues which develop over time during periods of oversaturated flows. For lane groups whose V/C exceed 0.95, calculated delays should be used cautiously. TRANSYT-7F, unlike the HCM, does have the ability to determine another MOE, maximum back of queues (MBQ). This MBQ is based on arrivals on red, also incorporating vehicles that may join the back of the queue as the queue dissipates during the allotted green time. While TRANSYT-7F cannot model the effects of spillback, this value provides a good indication of whether it is occurring.

TRANSYT-7F produces various other measures of effectiveness that are useful in evaluating intersection performance. These include total travel and total travel time, stops, and fuel consumption. In addition to these intersection MOEs, TRANSYT-7F outputs also provide route and system MOEs. These include total travel and travel time; uniform, random, total, average, and passenger delays; stops; speeds; fuel consumption; operating costs; and performance index.

Refer to http://mctrans.ce.ufl.edu/featured/TRANSYT-7F/ for additional details.

PASSER II. PASSER II-90, or Progression Analysis and Signal System Evaluation Routine, is not a simulation model like TRANSYT-7F or NETSIM, but rather utilizes a discrete, macroscopic, deterministic traffic analysis and signal timing model. (Although a simulation mode has been added as part of this version for analyzing uncoordinated operation.) This program is capable of handling isolated intersections or arterials only; it does not model signal grid networks.

In general, PASSER II-90 combines algorithms developed for this, and other, model(s) with HCM methodologies to analyze and optimize signals along an arterial. In particular, PASSER II-90 utilizes Webster's method as part of the optimization of cycle length and splits. Instead of simulation, PASSER II-90 uses algorithms to determine probability of queue clearance, percent green within the band, and all MOEs. PASSER II-90 is designed to select an arterial wide cycle length (it does not consider double cycling), intersection phase sequences which best serve progression, phase length, and offsets. One issue that many users may need to consider is that this version utilizes methodologies from the 1985 HCM, not the 1994 update to the HCM. MOEs estimated by PASSER include degree of saturation (v/c ratio), delay, stops, maximum queue length, fuel consumption, minimum delay cycle, bandwidth efficiency and attainability, and Levels of Service.

The main thrust of PASSER II-90 is to optimize a series of signals, allowing for the greatest possible bandwidth, for either one- or two-way flow, depending on the user's specifications. This goal differs from that of Synchro and TRANSYT-7F, which develop their optimization procedures around delay. The best cycle determined by PASSER II-90 is chosen to give the highest bandwidth efficiency, which may or may not correspond to the lowest delay. Unlike TRANSYT-7F, PASSER II-90 does consider different possible lead/lag and overlap phasing when optimizing.

PASSER II-90 calculates delay using variations of the uniform and random delay terms found in the 1985 HCM. Calculation of uniform delay is fundamentally the same as the HCM equation for dl, with an adjustment

made to account for progression allowing platoon arrivals during green, and queue formation and dissipation. Random delay is calculated as in the 1985 HCM, with the exception that the calculation may be performed for either a one hour or fifteen minute period. Random delay, as calculated in the HCM, is for a fifteen minute period only. The PASSER II-90 delay model calculates the total, or approach, delay, not stopped delay as defined in HCM level of service. HCM level of service threshold values are increased by a factor of 1.3 to account for this difference between stopped and approach delay.

PASSER II-90 also incorporates other areas and factors of the 1985 HCM. One such item is an assistant function which aids the user in calculating saturation flows based on HCM adjustment factors. Also, PASSER II-90 contains an algorithm that roughly models shared lanes. This includes whether the lane will operate as a "de facto" left turn lane, as in the HCM. There are also various methods in which PASSER II-90 may model permitted movement. The user is allowed to use the HCM (1985) model, their own, or several other developed models. If the user wishes to stay as close to HCM methodologies as possible, he/she should be aware that the default method used is not the HCM model, but the TEXAS A&M model.

PASSER II-90 also calculates the volume to capacity (v/c) ratio in the same manner found in the HCM. While saturation flow may be calculated using HCM methodologies, the importance of accuracy in this value cannot be overstated. As with the other models discussed, an incorrect saturation flow can have a measurable effect on the quality of results and recommended timing and offsets. Saturation flow in one crucial area where engineering judgment must be keenly used, through field studies or other methods, to assure accurate reflection of local, existing conditions. Users must also be cautious in saturated conditions, since spillback is not directly modeled and will not be taken into account.

Refer to http://ttisoftware.tamu.edu/fraPasserII_02.htm for additional details.

TSIS-CORSIM. The CORSIM (TRAF-NETSIM) model, originally named UTCS-1S, was developed in the early 1970's under the direction of FHWA. Originally designed for mainframe usage, TRAF-NETSIM was later converted to a microcomputer version and became part of the TRAF-family of models. The TRAF family of models is a set of simulation models, each representing a particular traffic environment, that when combined may represent an entire traffic system. NETSIM'S role in the TRAF family is to model the urban traffic environment (i.e. intersections), including signalization, stop signs, yield signs, buses, pedestrians, etc. In general, NETSIM is a surface street network (urban traffic) microscopic stochastic simulation model. NETSIM has no direct optimization feature.

Briefly, a microscopic model is one which models each vehicle as a separate entity, contrasted to the macroscopic models discussed which model groups or platoons of vehicles. Microscopic models tend, by their nature, to provide a more detailed model of the traffic environment and vehicle interaction. Stochastic, according to Webster's Dictionary of the English Language, is defined as "pertaining to chance or conjecture..., random". Therefore, NETSIM accounts for the randomness of the traffic, the mix of car and driver types, in an attempt to reflect the "real world".

An understanding of the stochastic nature of NETSIM is crucial in gaining insight into the nature, operation, and methodology of the model and how it relates to the HCM. First, recall that the HCM provides a set of equations where a specific set of traffic, roadway, and signal conditions will always result in the same capacities and delays. In NETSIM, the same traffic conditions will not always result in the same MOE values. By utilizing the randomness of the model, the traffic stream may be "re-mixed". NETSIM stochastically assigns turn movements, free-flow speeds, queue discharge headways, and vehicle and driver attributes, allowing for the same "traffic" to yield varying MOES. To account for this randomness of the model, it may be necessary to perform a statistically sufficient number of runs, averaging the results, to better reflect real world variation. It is readily realized that an arterial will not operate identically on any two days. One Friday is different from the next, which is different from the next, etc.

Vehicle movement in the model is based on car following and lane changing logic, and response to traffic control devices and other demands. NETSIM accounts for "driver behavior characteristics" (i.e. passive or aggressive), vehicle characteristics (up to 16 different vehicle types with different operating and performance characteristics), vehicle interactions, traffic control devices (pre-timed and actuated signals, stop and yield signs), street system geometry, buses, pedestrians, etc. NETSIM also allows for the traffic environment characteristics to change over time, such as changes in signal timings and traffic volumes.

Unlike the other models discussed, NETSIM does not utilize the HCM delay or critical degree of saturation equations. Whereas HCS is an attempt to use traffic attributes (volumes, signal timing, geometries, etc.) to predict the capacities, delays, queues, etc. with a set of equations and factors, NETSIM uses these traffic attributes to generate a simulation of the traffic flow, from which the MOEs are directly measured. That is, the amount of delay experienced by each car is physically measured, from which an average is determined (both stopped and approach). The MOEs of the simulation may be thought of as being measured in much the same manner as field measurements would be performed.

As stated, NETSIM has been in use since the early stages of transportation modeling, and has been used by many people to successfully and accurately reflect traffic flow. While NETSIM uses direct measurements, rather than predictions, to determine MOEs, any measurements are only as accurate as the simulation from which they are based. Therefore, calibration and validation of the simulation are crucial in the creation of an accurate model. This cannot be overstated for this or any other model. Items such as queue discharge characteristics, driver types, length of entry links, etc. may require study and engineering judgment when developing a model.

Refer to http://mctrans.ce.ufl.edu/featured/TSIS/ for additional details.

Highway Capacity Software (HCS). The HCS implements the procedures defined in the 2000 Update to the Highway Capacity Manual (HCM) from the Transportation Research Board (TRB). The software includes analysis modules on (1) Basic Freeway segments, (2) Weaving areas, (3) Ramps, (4) Multilane Highways, (5) Two-Lane facilities, (6) Signalized intersections, (7) Unsignalized intersections, (8) Arterials segments, (9) Transit, and (10) Freeway facilities analysis.

HCS-2000 and HCS+ were developed by the McTrans Center at the University of Florida as a typical Windows (all operating systems versions) installation.

The HCS **Signalized** Intersection module entry screen has been organized to consolidate data entry with the factors affected in the analysis. In this arrangement, the results of changing input data are readily apparent. The Report Pane will produce output similar to the HCM and previous versions of HCS which follow the Volume, Saturation Flow, Capacity and Level of Service worksheets.

Operational analyses will typically solve for Level of Service (LOS) for a given set of operational and geometric conditions. This type of analysis is oriented toward the evaluation of an existing facility or specific design proposal. The methodology uses the HCM Chapter 16 procedures.

Tru-Traffic (formerly Tru-Traffic) is a worksheet for drafting time-space or platoon-progression diagrams. It allows the user to see the entire diagram in colorful, high resolution on the screen. Although Tru-Traffic offers some automatic optimization options, it was developed with the idea that some decisions in signal timing are based on factors that cannot be quantified easily or accurately for a computer (e.g., driver perception, citizen complaints, queue length, local policies, etc.) and therefore must be made by a human.

Tru-Traffic allows the user to see one or more diagrams, easily modify any parameter (phase sequence, offset, cycle length, splits, etc.) for any intersection, and instantly see the effects of the change. Thus, the user can quickly optimize the parameters. On time-space and time-location diagrams, it automatically adjusts the green bands to show the traffic flow. On platoon-progression diagrams, it shows the flow density

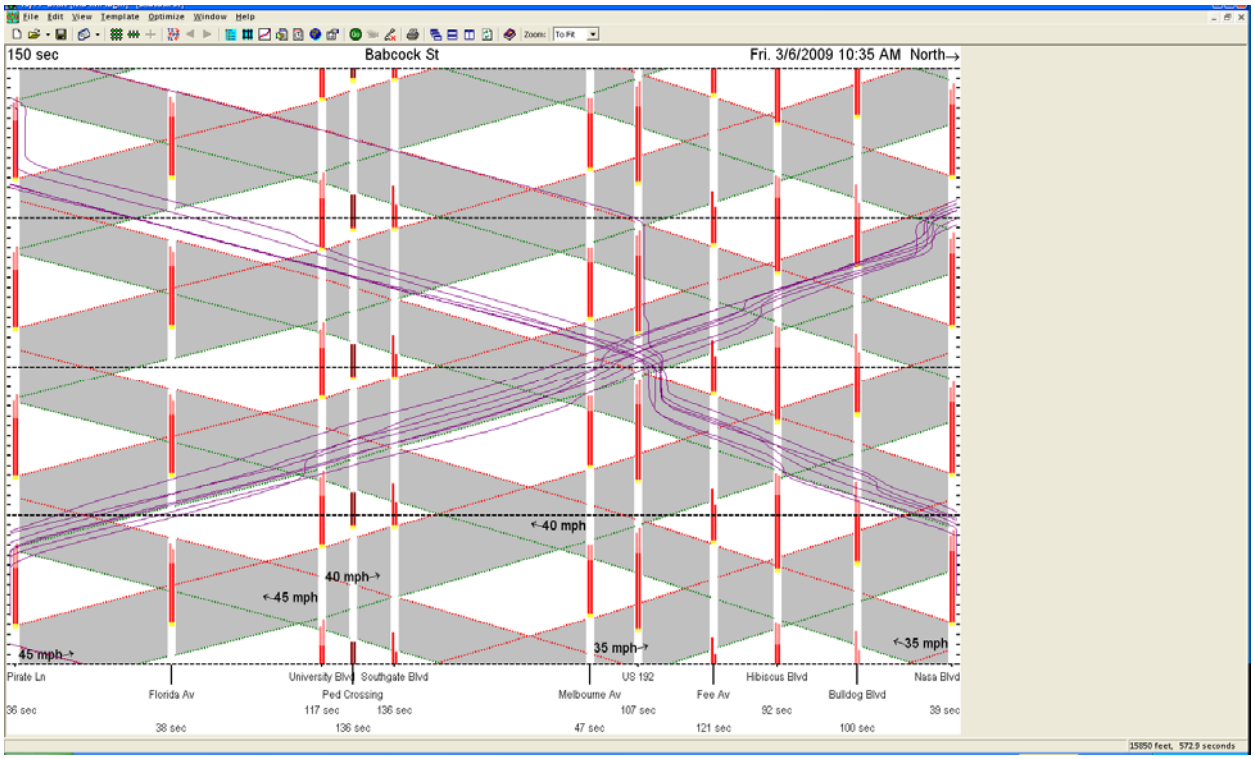
and queue lengths, much like the diagrams of PPD, the TRANSYT-7F post processor (except that the parameters may be changed interactively with the mouse or cursor keys, and the diagrams are displayed on the screen rather than just on the printer).

Tru-Traffic handles signalized networks or intersecting arteries by allowing multiple diagrams, each in its own diagram window, and each representing a different artery. The common intersections are "linked" across diagram windows so that the user may edit the parameters in any diagram window, and Tru-Traffic ensures that the common parameters between linked intersections stay concurrent.

Using a GPS Receiver connected to your computer will allow Tru-Traffic to track position and speed. The collected information may be used to:

- ✓ Calculate the distance between intersections,
- ✓ Lay out the Network View with high accuracy,
- ✓ Display your current location in time and space on the diagram window and in the Network View,
- ✓ Predict whether you will arrive at the next signal during the green time, and
- ✓ Record Trip Logs of travel along the artery. Trip Logs can be
- ✓ Plotted as trajectories on the diagram windows, graphically showing where delay occurs, which signals you're stopped at, and where you enter or leave the green bands. Before and after trip logs may be recorded in the same diagram data file, and you may select which ones are visible at any moment.
- ✓ Used to prepare comparative Travel Time and Delay Reports (before vs. after runs), which can easily be copied and pasted into word-processing documents or spreadsheets for detailed analysis. These can be very powerful tools of analysis for determining the effectiveness of a timing plan.
- ✓ Plotted as Speed vs. Distance or as Time vs. Distance plots
- ✓ Used to measure the actual travel distance between intersections.
- ✓ Used to calculate the "optimal" relative offset between intersections for a given direction of travel.
- ✓ Used to calculate the actual average speed between intersections

Exhibit 5-1 Travel Time Runs in Tru-Traffic



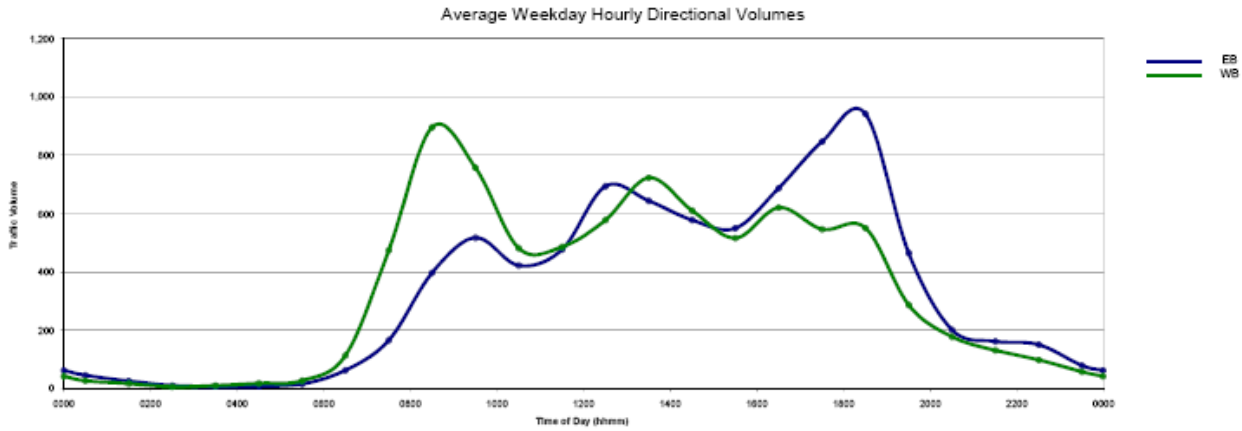
Timing Plan Needs

In order for a traffic signal system to operate under coordinated traffic responsive (TR) or time of day (TOD) control, it is necessary to develop various signal timing plans. For traffic responsive operation, the traffic control plan is selected based on the actual traffic demand along the corridor. System detectors transmit volume and occupancy data to the master controller which then selects the timing plan based on predetermined threshold values for various volume levels and directional preferences.

For TOD operation, the timing plan for varying volume levels and directional preferences is selected based on the time of day, day of week, and week of year. Traffic responsive operation has the advantage that it can change the timing plan to account for varying conditions if the traffic demand is different than that predicted for use in the TOD plan. More details on these operational modes is covered in later sections.

The number of timing plans required is influenced by a number of factors but largely depends on the traffic variability throughout the year, week and day. The following graphic illustrates traffic variability averaged over 7 days and is used to determine how many timing plans are needed and when to conduct the pattern changes.

Exhibit 5-2 Sample Average Weekday Hourly Directional Volumes



When the resources are available, the following timing plans should be investigated for three different volume levels with three different directional preferences, as follows:

Exhibit 5-3 Sample Directional Coordinated Timing Plans

Volume Level (TR)	Plan Number	Time of Day (TOD)	Directional Preference
Low	1	Low AM Peak	Inbound Flow
	2	Low Off Peak	Balanced
	3	Low PM Peak	Outbound Flow
Medium	4	Medium AM Peak	Inbound Flow
	5	Medium Off Peak	Balanced
	6	Medium PM Peak	Outbound Flow
High (Peak)	7	High AM Peak	Inbound Flow
	8	High Off Peak	Balanced
	9	High PM Peak	Outbound Flow

Implementation

The initial timing plans should be implemented and fine-tuned. This implementation should include, as a minimum, the following three steps:

- ✓ Field verification of the initial timings of each plan should be performed. This will include verification of cycle lengths, splits and offsets.
- ✓ Field assessment of traffic operations resulting from each plan. This will include observations of intersection operations for several cycles during peak hours and trial runs along both directions of arterials (at the prevailing speed) to ascertain progression. Changes to splits and/or offsets should be implemented as necessary.
- ✓ Reassessment of traffic operations resulting from revisions to the timing plans.

An accurate record of all field revisions to the timing plans should be prepared.

"After" Conditions

An "after" study of the new timing plans for comparison to the "before" study results should be performed. This effort should occur after a "stabilizing period".

Comparisons between "before" and "after" data should be performed for:

- ✓ System-wide measures-of-effectiveness output from the simulation models, and
- ✓ Field-collected measures such as travel time.

Also, refer to Chapter 4 for MnDOT's procedure to time a traffic control signal.

5.7 Traffic Signal Control Systems

System Concept

A system may be defined as an arrangement or combination of interacting or interdependent parts which form a unified whole serving a common purpose. The system concept as related to traffic signal control includes the methods, equipment, and techniques required to coordinate traffic flow along an arterial or throughout an area.

System Objective

The major objective of a traffic control system is to permit continuous movement and/or minimize delay along an arterial or throughout a network of major streets. This involves the selection, implementation, and monitoring of the most appropriate operational plan. Basically, a traffic signal system provides the appropriate and necessary timing plans for each intersection in terms of individual needs as well as the combined needs of a series of intersections.

Relationship of Timing Plans to Traffic Control

In the system concept a timing plan is defined by a combination of control parameters for one or more intersections based upon an analysis of demand. Timing plans can be provided as a function of equipment at the local intersection, the central control point, or both. Timing plans consist of:

1. *A system Cycle*. A specific cycle length is imposed throughout the system covered by the timing plan.
2. *Split*. All intersections in the system have defined splits which are the apportionment of the cycle to the various phases present at that intersection.
3. *Offset*. Each intersection has a unique offset. The offset is the relationship of the beginning of the main street green at this intersection to a master system base time. Offsets are generally expressed in seconds. Properly established offsets along a street can potentially provide for smooth traffic flow without stopping.

Basis of Selecting Timing Plans

The selection parameters which define timing plans include:

1. *Historic Data* Time of Day information compiled from traffic counts to reflect traffic volumes for specified time of day (morning peak, midday, afternoon peak, etc.) and day of week.
2. *Current Data* Real time on-street volumes from traffic detection equipment.
3. *Special Data* Special events, emergency route assignment, special right-of-way preemption (fire equipment, ambulances, buses, etc.)

Types of Traffic Signal Control Systems

Many combinations of methods, equipment, and techniques can comprise a traffic signal control system. Generally, these systems fall into the following basic types.

Time Based Coordinated (TBC) System

This form of coordination utilizes non-interconnected controllers with auxiliary devices called time based coordinators. These devices use the power company supplied frequency to keep time very accurately. Various timing plans can be established with time of day and day of week plan changes. Since all intersections use the same power source, the time-based coordinators provide coordination without physical interconnection.

Global Positioning System (GPS) receivers have been used for several years to provide a clock sync to ensure TBC is maintained.

Interconnected Pre-timed System

This type of system was originally developed for electromechanical controllers, but can also be used with some of the newer controllers. Local intersections are physically interconnected (usually by a 7-wire cable) to ensure coordinated operation. The system provides automatic re-synchronization should a signal go "out of step". The number of timing plans is a function of the number of dials and the number of offsets and splits per dial; the most common system consists of a three-dial, three-offset, one-split combination. Timing plans are normally selected by a time clock or time dependent programming device. The local controller for one intersection may act as master controller for the system.

Traffic Responsive System

Basically, this is an interconnected system utilizing a master controller for pattern (Cycle/offset/splits) selection. Traffic detectors are used to sample directional volumes and detector occupancy. Volume and occupancy metrics determine which of the available patterns is selected (i.e., inbound, outbound, or average) based on predetermined thresholds. The master controller may be an analog or a digital computer.

Interconnected Actuated Systems

Generally a small system with a master-slave relationship (i.e., two or more fully-or semi-actuated local controllers with one acting as system master and controlling cycle length for the other controllers). Offset capability is limited. A variation of this system uses a system master, coordinating units, and local actuated controllers. The master may be traffic responsive or combination of time clocks.

Traffic Adaptive System

Traffic adaptive systems perform "real-time" adjustments to the cycle length, splits and offsets in response to traffic demand. Traffic adaptive systems require extensive detection inputs. Complete and accurate traffic flow data must be gathered, processed and communicated to the central computer.

Advanced Traffic Management Systems (ATMS)

ATMS are capable of monitoring and controlling thousands of intersection controllers using state of the art architecture like TCP/IP and NTCIP. ATMS offer complete traffic and data management including real time field reporting for multiple users over distributed local and wide area networks and remote access.

ATMS offer scalable software solutions that support a range of users including:

- ✓ School zone flashers
- ✓ Freeway management
- ✓ CMS, VMS, DMS
- ✓ CCTV surveillance
- ✓ HOV lane control
- ✓ Reversible lane control signals

- ✓ Real-time split monitoring and time space reporting
- ✓ Incident detection
- ✓ Light rail control systems
- ✓ Transit priority systems
- ✓ 1.5 generation timing plan development using Synchro or PASSER
- ✓ 2.0 Generation control (Traffic Responsive and Traffic Adaptive)
- ✓ Integrated video detection
- ✓ Real time preemption log retrieval

Time-Space Diagrams

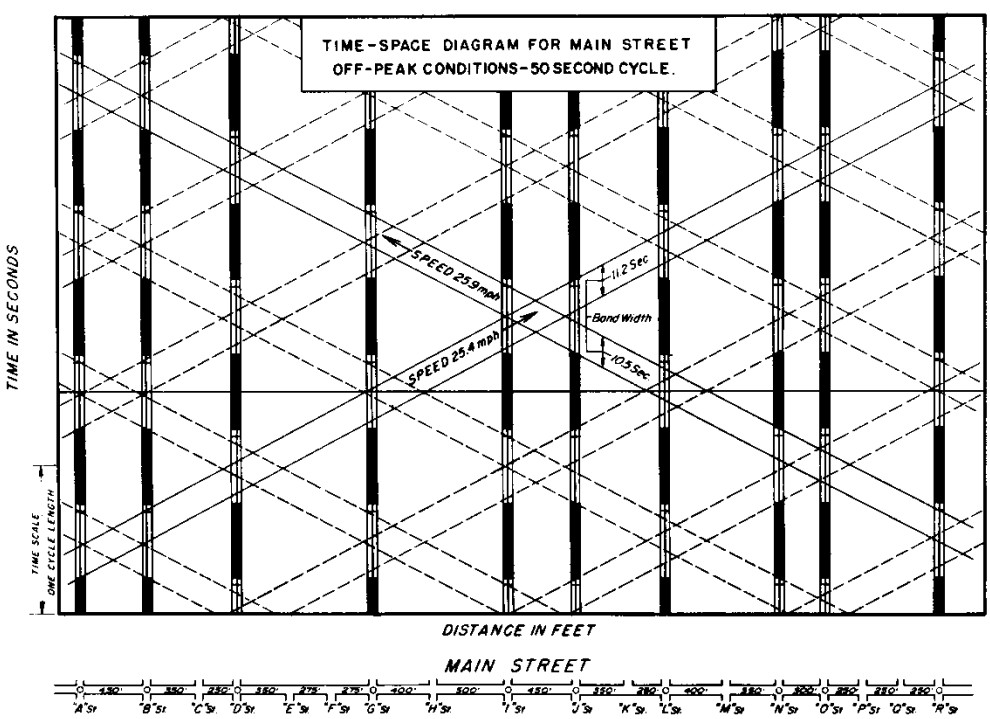
These are prepared to determine the offsets on individual intersections.

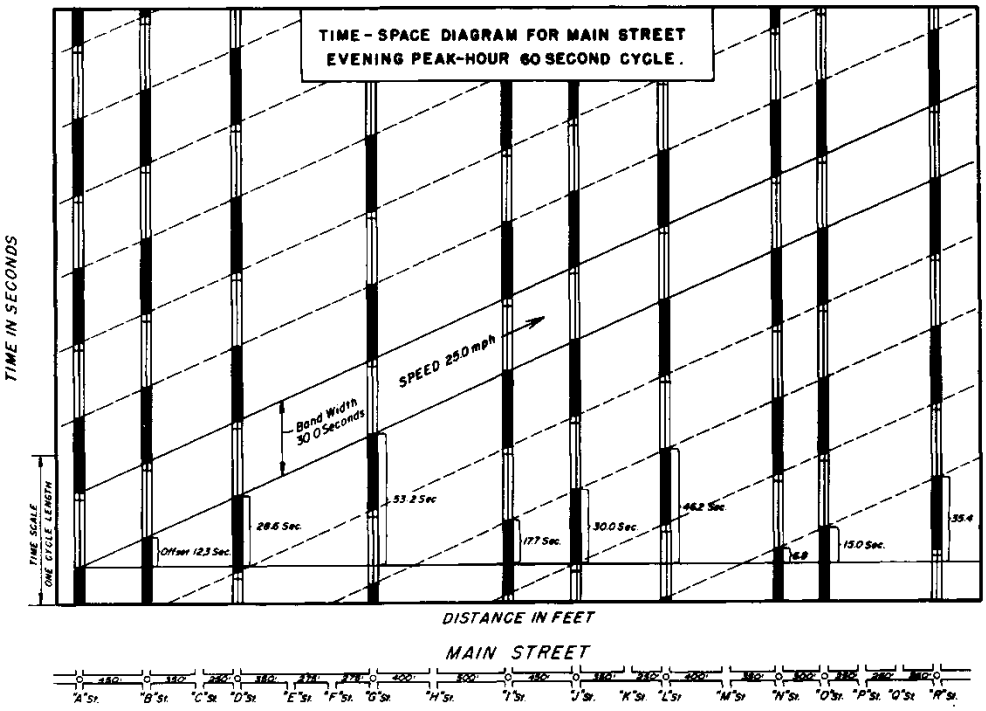
A time-space diagram is a chart on which distance is plotted against time. The location of each signalized intersection is plotted along one axis. At each such point the signal color sequence and split are plotted in such a manner that through bands are available for each direction of traffic flow. The slope of the through band (distance divided by time) is the speed of progression, and width indicates the time available for a platoon traveling through systems.

For two-way streets, the diagram is usually prepared to give equal consideration to each direction of travel. Where appropriate types of program controllers are available, separate peak-hour diagrams are prepared for streets carrying heavy directional peak volumes; these will favor travel in the peak direction. The cycle length may be changed (for the entire system) and the offsets are changed through the use of time clocks in the master controller. Sample time-space diagrams for off-peak and evening peak periods are shown in the figures below.

When a coordinated system is established for a certain speed during all periods of the day, supplemental signs may be erected which inform the driver of that speed.

Exhibit 5-4 Sample Time Space Diagrams





Complex Timing Systems. Development of timing parameters and programs for the more sophisticated signal systems is very specialized and depends greatly on the specific system components and configuration. Timing techniques, methodology, and philosophy are receiving considerable attention. Extensive research in these areas is continuing. Computer programs have been developed for timing networks such as Synchro.

Control Philosophies for Computerized Traffic Signal Systems

The progress of the state of the art in traffic signal control systems is a function of the technological development of computer applications and control philosophies. Generally, control philosophies may be categorized as follows:

First Generation

These programs are basically of the table look-up type. A number of essentially fixed timing patterns have been precomputed and stored. Control plans are selected based on time of day or on sensing certain demand parameters at strategically located detectors. As threshold positions are reached, alternative predeveloped and stored control plans are implemented. This procedure is used in most of the presently operational digital computer controlled systems.

Second Generation

This type of control program is still based on a background cycle, but provides for on-line, real time computation of control plans and strategies. It utilizes a prediction model to predict near-term (e.g., 15-minute) changes in traffic demand. Current conditions and these predictions are then used in an on-line optimization program to compute splits and offsets.

1.5 Generation Control

1.5 GC utilizes on-line data collection and predetermined algorithms to generate input data to the TRANSYT-7F timing program. A new timing plan is computed and compared to the existing timing plan. Currently, the

operator must decide whether the improvement is worth implementing on either a temporary or permanent basis.

Comparison

The FHWA sponsored extensive research in evaluating the first and second generations of control under the Urban Traffic Control System (UTCS) program. The abstract of the Executive Summary of the Evaluation Study states:

"The First Generation...was found to be operationally effective, was the least expensive to apply, and should be given primary consideration for implementation. Second Generation proved effective on arterials, was only slightly more costly to implement than [first generation], and should be given consideration for areas with substantial arterial development."

6 SYNCHRO AND SIMTRAFFIC

The information following this sheet is a handout from the Synchro and SimTraffic training manual.

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HANDOUT

Synchro and SimTraffic

Training Course

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1. COURSE INTRODUCTION

1.1 Background

This course and workbook cover the Synchro signal timing and analysis software, the SimTraffic simulation and animation package and the 3D Viewer. This course is broken down into the following levels:

- ✓ **Level I**. The Level I course material can be found in Section 2 through 3 of this workbook and is a 2-day class. The objective of this course is to familiarize the participants with the input requirements for Synchro and SimTraffic and to review and understand the outputs. Through the use of a hands-on example, students will build a Synchro file of a signalized intersection network. Students will also learn to optimize this network, review and modify the results with the time-space diagram, overview of animation in SimTraffic and creating reports.
- ✓ **Level II**. The Level II course material can be found in Section 4 of this workbook. This course is intended for individuals with working knowledge of Synchro and SimTraffic. Attendance at any of the Level I courses satisfies this prerequisite for the Level II course but is not required. The focus of the course will be on Synchro calculations, optimizations, and advanced example problems.

1.2 Course Objectives

The main emphasis of this course will focus on building, optimizing and analyzing a signal network with Synchro and simulating and animating the results with SimTraffic.

At the end of each course, you will be able to:

Level I

- ✓ Create a map of the street and intersections in the Synchro program with and without the use of a background map (DXF or Bitmapped).
- ✓ Enter the appropriate lane, volume, timing, simulation and detector information into Synchro.
- ✓ Optimize individual intersection cycle length, splits and offsets within Synchro.
- ✓ Optimize a network of signals for cycle length and offset.
- ✓ Display and modify Synchro's time space diagrams.
- ✓ Understand the results displayed in the Synchro program.
- ✓ Integrate Synchro data with the SimTraffic and 3D Viewer Programs.
- ✓ Create reports to display timing information and measures of effectiveness.

Level II

- ✓ Understand the basic calculations used in Synchro to provide a better understanding of what is being output by the program.
- ✓ Understand how Synchro performs an optimization.
- ✓ Apply some of the features that are available, such as the UTDF.
- ✓ Create some advanced examples of unique coding situations in Synchro and SimTraffic.
- ✓ Apply some workarounds for Synchro and SimTraffic

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1.3 Synchro

Synchro is a complete software package for modeling and optimizing traffic signal timings. The key features of Synchro include:

- ✓ Capacity Analysis. Synchro models intersection capacity, delay and LOS for signals, unsignalized intersections and roundabouts based on the Highway Capacity Manual (HCM, 2000 and 2010 versions).
- ✓ Optimization: Synchro allows you to quickly generate optimum timing plans for isolated intersection and networks of signals to minimize delays (see page 3-5).
- ✓ Actuated Signals: Synchro uses a Percentile method to model actuated signals (see page 4-1). Synchro can model skipping and gap-out behavior and apply this information to delay modeling.
- ✓ Time-Space Diagram: Synchro has colorful, informative Time-Space Diagrams. Splits and offsets can be changed directly on the diagram (see page 4-7).
- ✓ Integration with SimTraffic, CORSIM (version 5) and HCS (version 3): Synchro features preprocessor to these software analysis packages. Enter data once with easy-to-use Synchro, and then perform analyses with these software packages.

As noted in text to the right, Synchro is **based** on the methods of the HCM. However, there are important differences between Synchro and the HCM.

Synchro basically uses the same methods for Saturation Flow and Volume adjustments. However, the 2010 HCM now includes a comp engine to calculate effective green times. Synchro uses its Percentile Method since its inception when the software was released in 1994.

Synchro is a macroscopic traffic software program that is **based** on the signalized intersection capacity analysis as specified in the Highway Capacity Manual (HCM). Macroscopic level models represent traffic in terms of aggregate measures for each movement at the intersections. Equations are used to determine measures of effectiveness such as delay and queue length. Traditional HCM based models do not account for "bottleneck" situations where upstream traffic deficiencies reduce the amount of traffic reaching downstream intersections. For example, if an upstream bottleneck occurs, macroscopic models assume the demand volume reaches the subject intersection.

The HCM was recently updated (the 2010 HCM). Synchro 8.0 does include a report for the past 2000 HCM and the current 2010 HCM. In addition, Synchro has a data screen for the 2010HCM methods (one does not exist for the 2000HCM).

Macroscopic Model Limitations

There are a number of important limitations to macroscopic models that users must be aware of. Below is a summary of, but not an all inclusive list of some limitations of Synchro, the HCM 2000 and the HCM 2010 Computational Engine.

Limitation	Synchro 8.0	HCM2010	HCM2000
Turn Pocket Overflow	All three methods have this limitation. If vehicles are spilling out of a turn pocket or thru vehicles are blocking a turn pocket, this delay that would occur in the field is not included in the model's delay output.		
Spillback and Starvation Delay caused by closely spaced intersections	Synchro includes a method to model this delay when intersections are close to each other.	The HCM methods do not include any delay for queue spillback or starvation.	
Actuated Green Time Calculations	Synchro determines actuated greens based on a Percentile method.	The HCM 2010 includes a comp engine that determines actuated greens.	The HCM2000 methods do not calculate the actuated green. This is an input the user is expected to enter.
Right Turn on Red Adjustment	Synchro calculates a RTOR value and increases the capacity.	In the HCM methods, the RTOR is a volume input by the user and becomes a volume reduction (not a capacity increase).	

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Refer to the table in section 4.1 for additional situations where the Synchro results will vary from the HCM Methods.

1.4 SimTraffic

SimTraffic is a microscopic model used to simulate a wide variety of traffic controls, including a network with traffic signals operating on different cycle lengths or operating under fully actuated conditions. SimTraffic also models unsignalized intersections, roundabouts and channelized right turn lanes.

In SimTraffic, each vehicle in the traffic system is individually tracked through the model and comprehensive operational measures of effectiveness are collected on every vehicle during each 0.1-second of the simulation. Driver behavior characteristics (ranging from passive to aggressive) are assigned to each vehicle by the model, affecting the vehicle's free-flow speed, queue discharge headways, and other behavioral attributes (see the SimTraffic driver parameters, page 4-32). The variation of each vehicle's behavior is simulated in a manner reflecting real-world operations.

Since SimTraffic is microscopic, the model measures the full impact of queuing and blocking. This is a situation where SimTraffic may show more delay when compared to Synchro.

Synchro is used as the input editor for SimTraffic. But, as noted in the text of this manual, the results could be quite different. This is due to the nature of how the models determine measures. Synchro is macroscopic and SimTraffic is microscopic. Generally, microscopic models are more realistic, however they also are more time consuming and do not provide optimized results.

Microscopic Model Disadvantages

SimTraffic is categorized as a microsimulation model. For all if it's strengths, there are disadvantages or limitations to consider. Some of these include, but are not limited to:

- ✓ Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed.
- ✓ SimTraffic does not optimize signal timings, it performs an experiment on the data that it is given. If changes are required, these must be done manually (in Synchro) and the model simulated again.
- ✓ Calibration of simulation models is a time consuming, trial and error process. There is no single answer on how to calibrate a model. It is case dependent for the study area.
- ✓ A single error or modeling problem can cause inaccurate results at all study intersections. This problem may create an artificial bottleneck preventing vehicles from moving downstream to be measured.

1.5 Which Model to Use?

The intention is to use Synchro and SimTraffic as companion models. Synchro to determine macro level LOS and delays, and SimTraffic to simulate and animate to determine the 'problems' that may not be fully realized with a macro-level model.

In summary:

- ✓ Synchro may show more delay when upstream bottlenecks exist.
- ✓ SimTraffic may show more delay when queuing and blocking problems exist.

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The Additional Instructions for Training are only required in the training room. On your PC at your office, the license will be activated over the internet (or phone) and these additional steps will not be required to launch the software.

1.6 To Run Synchro

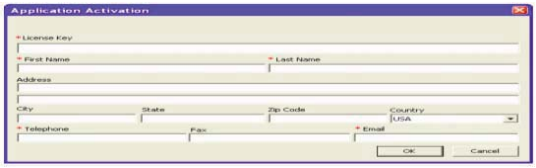
1. Select the Start Menu, then choose **Programs→Trafficware→Synchro**.
2. The first time using Synchro you will be asked for a product key code. This number will be listed on your invoice or press [Use as Demo] if you want to use the demo version.

1.7 Additional Instructions for Training

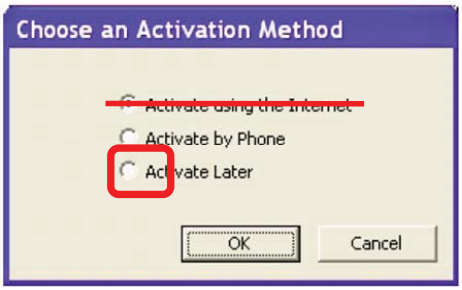
The software used for the training course is a temporary license key. Each time the software is launched in the training room, you will be asked to activate the software. Peform the following steps:

- ✓ Double click on icon on desktop
- ✓ Check the box to Accept the License Agreement

- ✓ Choose "Activate"
- ✓ Select OK on the Application Activation (information will be filled out for you)



- ✓ Choose "Activate Later"



- ✓ Select OK multiple times to open Synchro

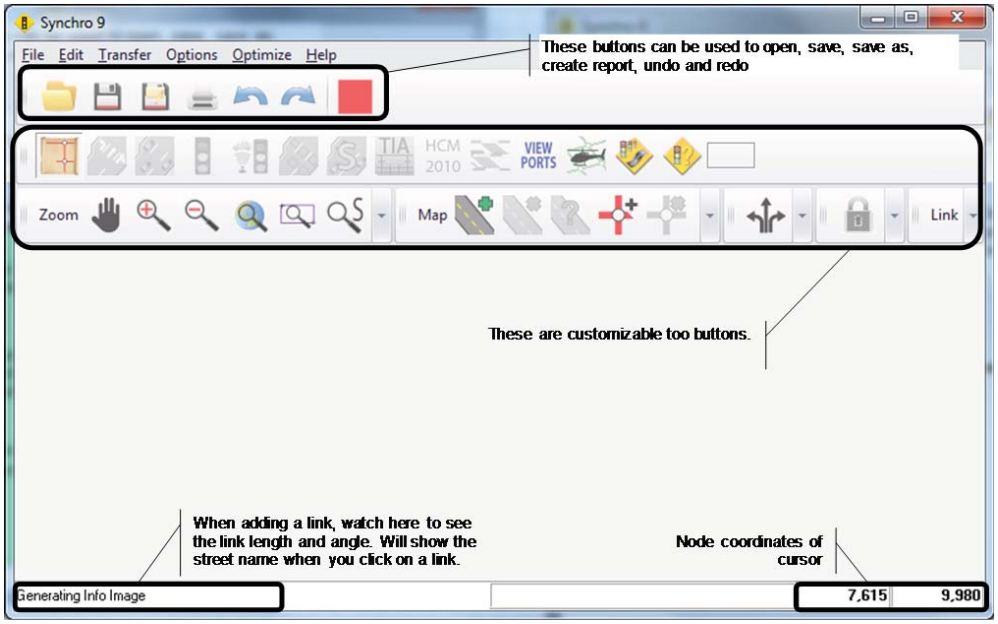
HANDOUT

2. LEVEL I – DAY 1

2.1 Map View Input

The **MAP** view includes the drawing area and the map information buttons. The drawing area of the **MAP** view is where you create your network links and nodes.

To activate the **MAP** view, press the ***Map view*** button or press the [F2] key from anywhere in the program. By default, Synchro will show the **MAP** view when you start the program.



How to Add a Link

1. Select the ***Add Link*** button or press the **[A]** key.
2. Position the mouse cursor on the **MAP** view where you want the link to start, and click the left mouse button. The status indicators, at the lower-right corner of the settings, show the East and South coordinates in feet (meters). Note: To cancel adding a link, press [Esc].
3. Release the mouse button and move the cursor to the position on the map where you want the link to end. Click the left mouse button again. Refer to the status bar at the bottom of the settings to see the length and direction of the link

To draw links that are orthogonal or at 45 degrees, hold the [Shift] key while creating your link.

To draw a curved link, right click on the link and choose **Add-Curvature**. Use the squares to move the link to the desired curvature. Synchro will recalculate the link distance.

How to Add an Intersection

To create an intersection, simply create two or more links that cross each other. If you have a node that is connected by exactly two links, this is defined as a bend node. Three or more links (up to eight) will create an intersection node.

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NEW

In version 9.0, the toolbar can now be moved throughout the map and can be customized based on user preference.

In the Map view, hold your cursor over the button to see a pop-up text description of the button.

It is not necessary to determine the exact length of the links. It is sufficient to determine the distance to within 20 or 30 feet (6 to 8 meters). The minimum distance for a link is 70' (center of intersection to center of intersection distance).

Synchro uses the link distance and speed to calculate travel time. The travel time is used in the determination of arrival patterns, which is then used in the delay calculations.

When creating external links, make these long enough to hold the queues that would build during a simulation. In SimTraffic, the queues are limited by the link distances.

Intersections cannot be created on curved links. Be sure to add all intersections, then curve links.

HANDOUT

HANDOUT

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In Version 6 and later of Synchro, bend nodes are needed less frequently due to the use of curved links. The main purpose of bends now will be to create a downstream taper.

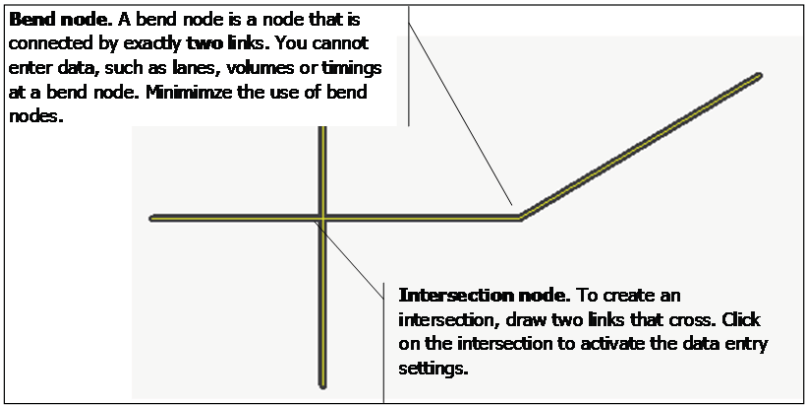
Create a bend at the location of a mid-block lane drop (or add).

To draw a link that crosses a link and does not create a node (overpass/underpass), hold the [Ctrl] key while drawing the link.

If you make a mistake, Synchro will let you Undo the command. Synchro remembers the last 100 commands (such as adding a link, optimizing splits, etc). You can also Redo. Use the buttons on the toolbar, the File Commands under Edit, or [Ctrl]+Z to Undo and [Ctrl]+Y to Redo.

Bends

A node with exactly two links is a bend. A bend is a special case of an unsignalized intersection.



Bend nodes increase the time for calculations. Excessive bends and short links cause SimTraffic to simulate at a slower rate.

How to Delete a Link

To remove a link from the map:

1. Select the link by clicking on it with the left mouse button.
2. Press [Delete] or select the ***Delete Link*** button .
3. Select [Yes] to the question, "Delete Link, are you sure?"

The link will be removed from the screen.

How to Delete an Intersection

To remove an intersection from the map:

1. Select the intersection by clicking on it with the left mouse button.
2. Press [Delete] or select the ***Delete Node*** button .
3. Answer [Yes] to the question, "Delete Intersection, are you sure?"

Any through links going through this intersection will be joined together. Any other links going to adjacent intersections will be shortened to preserve data at adjacent intersections. Any joined links will be redrawn.

How to Move an Intersection or External Node

To move an intersection or external node on the map:

1. Select the ***Move Node*** button or press the [M] key.
2. Select an intersection, or the end of an external link, by clicking on it with the left mouse button. Note: If you decide to cancel moving a node after starting, you can cancel the operation by pressing [Esc], or clicking the mouse button at the original node location.
3. Drag the intersection, or node, to the new location and click the left mouse button.

HANDOUT

If an external node is moved onto an existing intersection, or node, it will be combined with that intersection, or node. Intersections cannot be moved onto another intersection or external node.

When moving an intersection, it is possible that the realigned links will have new directions in such a way that lane groups will be changed. For example, if the relative angle between two links is changed from 180º to 90º, there will no longer be a through lane group for these links. Synchro preserves the lane group data. If a movement changes from NBL to NBT, for example, the data for NBL will be transferred to NBT.

The on-line Help is always available in Synchro and SimTraffic. From anywhere in the program, press the [F1] key to bring up the Help file.

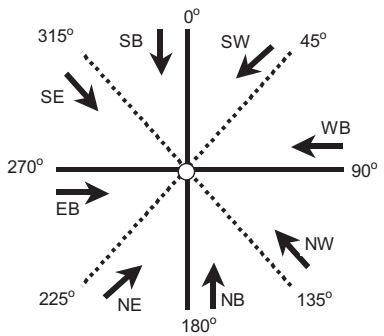
The Help file is fully searchable (PDF format). Click on the Search button and perform a search on your keyword or text.

Link Directions

Links are directional. The angle is shown in the lower left hand corner of the **Map View** as you are creating the link. North is always up (zero degrees). Directions are then based on the angle as noted in the table and graphic below.

Remember, hold the [Shift] key to create links that are Orthogonal (N, S, E, W) or at 45 degree angles.

The graphic and table assume drawing from the center node point. For instance, a link created at 35 degrees would be labeled as SW (toward the intersection) and NE away from the intersection. Synchro will allow up to eight links.



Link Angle	Approach Heading	
	Towards Int.	Away from Int.
326 - 34	SB	NB
35 - 55	SW	NE
56 - 124	WB	EB
125 - 145	NW	SE
146 - 214	NB	SB
215 - 235	NE	SW
236 - 304	EB	WB
305 - 325	SE	NW

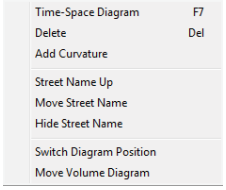
See page 2-10 for details on changing the name of the approach direction.

Use the Transform Map button to rotate an entire network.

The exception to the above table is when you have two links within the angle ranges. For example, if you have a link at 0 degrees and one at 34 degrees. Based on the table, both would be SB towards the intersection. However, Synchro will only allow one link to be labeled as SB. Therefore, the link closest to zero degrees will be labeled as SB. The other will be labeled with the closest diagonal direction.

Link Menu Options

Synchro now includes additional options from the Link Menu. To access the Link Menu, right click on the link within the Map View. The new options in the Link Menu include; Street Name Up, Move Street Name, Hide Street Name, Switch Diagram Position and Move Volume Diagram.



Select Intersection

Use the ***Select-Intersection*** button or the [F8] key to bring up a list of the intersections in your network. This will bring up the **SELECT INTERSECTION** window.

Choosing an intersection from the list and pressing [OK] will switch the current window to that intersection. The **Map View** will be centered on the selected intersection.

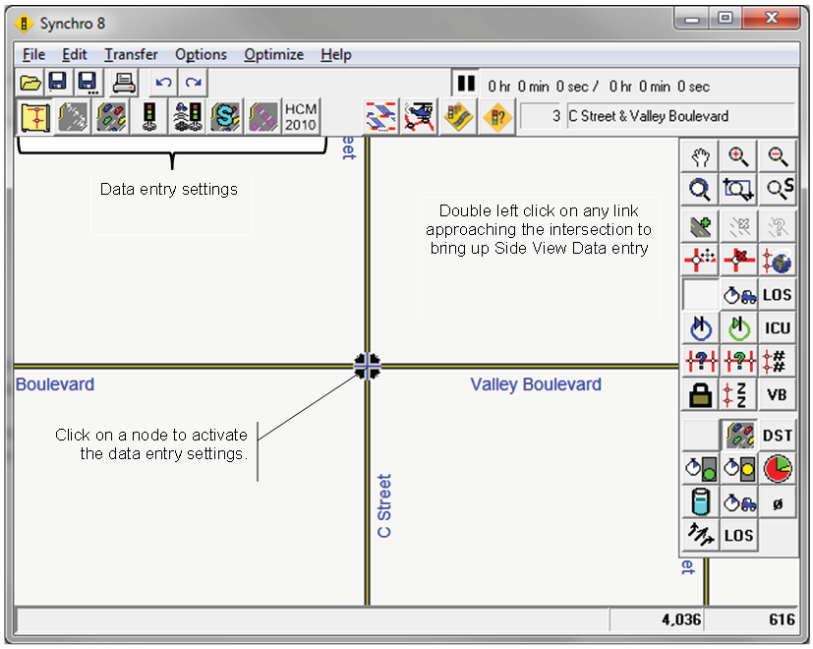
Note: To center the MAP view, press [Ctrl]+[C] and the click where you want the map to be centered.

2.2 Data Entry Settings

Data can be input, edited and viewed with the data entry setting buttons after links and nodes have been created in the **MAP** view.

HANDOUT

The data entry buttons are grayed out and not accessible until either a link or node is selected on the map.



Full View Data Entry

Data entry in Synchro can be performed with a traditional full screen view or a **MAP** view side entry. In full view data entry, the **MAP** view will disappear. To activate, highlight an intersection from the **MAP** view and select the desired data entry button along the top of Synchro.

When in the full view of the **PHASING** and **TIMING** settings, press the [**F9**] key to move focus between blue (directional) and yellow (node) sections.

The full view data entry screens will show all available movement headings. The available movement headings will depend on the layout of the links. For instance, a T-intersection will have 6 columns visible and a 4-leg intersection will have twelve columns visible.

The direction headings are based on the angle of the link as drawn in the **MAP** view (north is always up, or zero degrees).

Side View Data Entry

In addition to a full view data entry screen, data can also be entered with a side view screen. This view displays the data entry rows on the left side of the **MAP** view allowing you to see the data update as you enter. To activate the side view data entry, double click on a link approaching an intersection.

A background image is just that… an image that lies in the background. The image is an excellent tool to help you quickly create your network. However, it will have no impact on your results.

Background Images

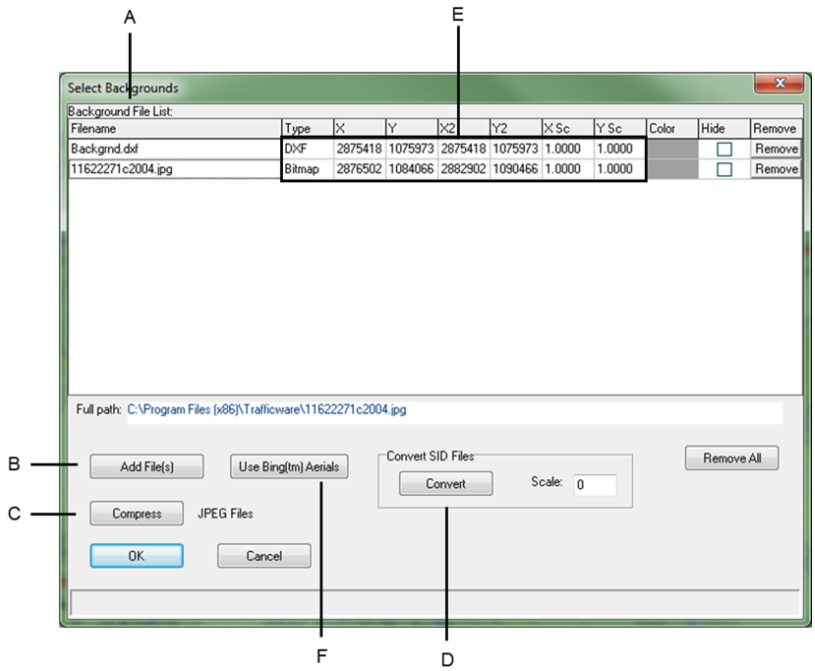
Synchro allows the ability to import a DXF, SHP, SID, JPG or BMP file as a background image. In addition, version 8.0 has added the ability to import a background via Bing™ images.

HANDOUT

Select Backgrounds Window

To add, remove, or adjust backgrounds; select **File→Select Background**.

If no files are attached, the user is prompted for a file or multiple file(s). The files can have the extension JPG, JPEG, BMP, DXF, or SHP as defined above.



DXF and SHP files are scaled images. Therefore, you simply import these and they will be at the proper scale.

A JPG and BMP is a pixilated image that requires scaling.

To set the scale and coordinates for a BMP or JPG, double click on the coordinates of the file. This is Item E in the image to the right.

The list of files is shown in the Background File List as shown as "A" above. This file list includes the following:

- ✓ Filename is the background image filename including the path.
- ✓ Type is the type of file (Bitmap, SHP, DXF, JPG).
- ✓ X, Y is the Synchro coordinate for the upper left hand corner of the image.
- ✓ X2, Y2 is the Synchro coordinate for the lower right hand corner of the image.
- ✓ X Sc, Y Sc is the image scale factor.
- ✓ Color allows you to change the color of a GIS shape file.
- ✓ Hide will hide the background image when checked.
- ✓ Remove will remove the image from the background.

Use the Add File(s) button ("B") to select one or more files.

The Compress JPEG Files button ("C") will prompt you for JPEG files. The selected files will be loaded and resaved with higher compression, but less quality.

The Convert SID files area ("D") provides access to the MRSIDDECODE.EXE, freeware utility. This is an unsupported DOS tool to help convert SID files into JPG.

See the following section for item ("E") setting the bitmap scale and offset. See the section below for item ("F") on importing and image from Bing™.

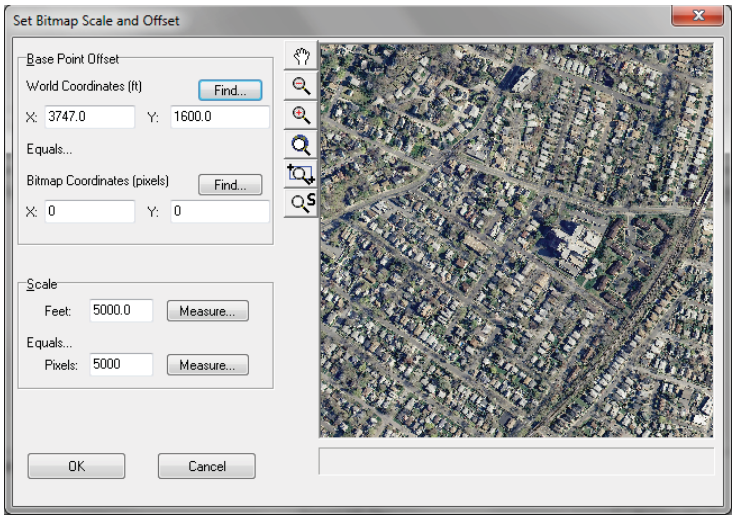
This Compress function will alter your existing JPG files and reduce the image quality. Use this feature to reduce the file size of background bitmaps.

HANDOUT

HANDOUT

Set Bitmap Scale and Offset

When loading a bitmap file (bmp or jpg) it is necessary to set the scale and base point. From the Select Background window, double click the scale settings ("E") to set the bitmap scale and offset. The SET BITMAP SCALE AND OFFSET window will appear as shown below.



The upper-left corner of the bitmap will have bitmap coordinates (0,0) in pixels. In an existing Synchro file, it is necessary to match a point on the bitmap to a node in the Synchro file.

1. Click [Find] for world coordinates and select an intersection on the Synchro map. This will set the World coordinates for the base point
2. Click [Find] for bitmap coordinates and select the point on the bitmap in the center of the previously selected bitmap. This will set the Bitmap coordinates for the basepoint. The bitmap will be placed so that the bitmap intersection is coincident with the Synchro intersection.

It is necessary to set the scale of the map. To help set the scale, Synchro allows you to measure distances on the bitmap and in an existing Synchro map.

1. Click [Measure] for Feet (or Meters) and select the first point on a link of known length. Within a new file, simply type in the distance of a known street length.
2. Click on the second point of the Synchro point with known length. This will set N in the formula, N feet per M pixels.
3. Click [Measure] for Pixels and select the starting point of the same link on the bitmap.
4. Click on the second link point on the bitmap. This will set M in the formula N feet per M pixels.

It is very important to keep the size of the files used as small as possible. All of the bitmaps and other files are loaded into RAM and accessed whenever the map view changes.

You can hide/unhide images of interest to help keep the PC memory footprint reasonable.

Using Bing™ to Add a Background Image

Synchro 8 now allows you to import images directly from Bing™. This feature will greatly assist in importing internet based images and ensuring that the scaling is appropriate. It will also be useful to create a mosaic of images that will properly align. To use this option, an internet connection must be available during the import (not necessary after the image is captured).

HANDOUT

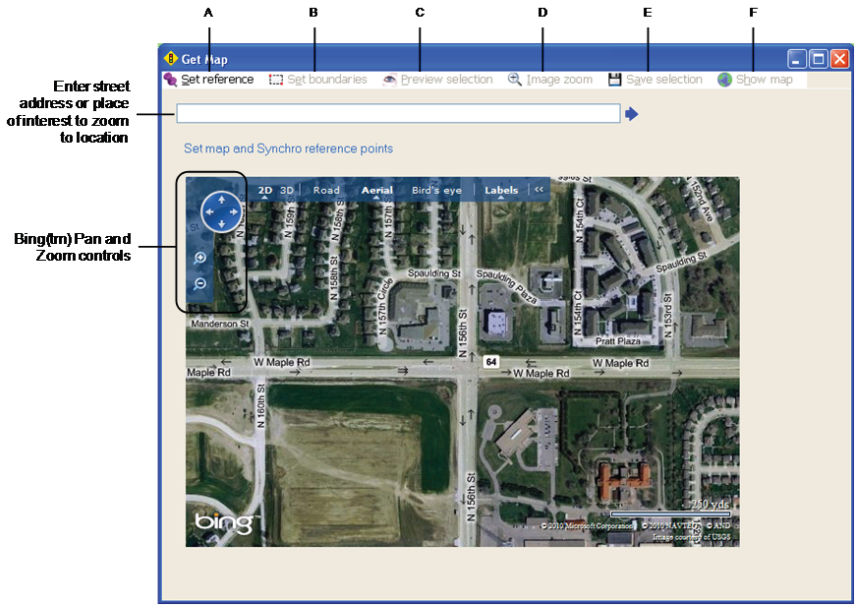
HANDOUT

HANDOUT

In a new or existing Synchro file, use the command select **File→Select Background** and select the **Use Bing ™ Aerials** button.

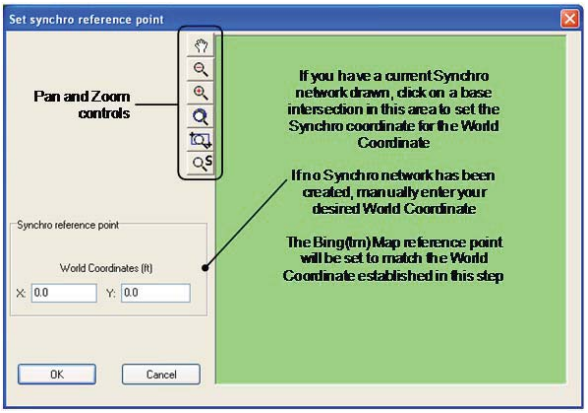
After selecting the Use Bing™ Aerials button, there is a new window **Get Map** dialog (see below) that uses Bing™ (aka Virtual Earth).

Get Map Dialog Options



Set Reference

After pressing **Set Reference** menu ("A" in the figure above), click the mouse on the Bing™ map to choose a reference point. You will see a pushpin on the selected point followed by a Set Synchro Reference Point window. Select a corresponding point on the Synchro MAP View or to manually enter a World Coordinate (see the image below). The Map and Synchro points will denote the same geographic point to tie the world map to the Synchro coordinates.



Set Boundaries

Press the **Set Boundaries** menu ("B" in figure in above) and choose the 1st and 2nd boundary points and set their position on the Bing™ map by clicking the mouse in the opposite corners of the desired map location. The boundary points will be shown as red pushpins and will mark the map area to be converted to the background image.

HANDOUT

Preview Selection and Image Zoom

Press the **Preview Selection** menu ("C" in the figure above) to preview the map and adjust its scale by clicking on Image Zoom menu and choosing **Zoom In/Zoom Out** (see next step). Bing™ does not provide the maximum zoom for all locations, so previewing the map and using Zoom Out if necessary may guarantee that the map will be saved correctly to the background image.

Image Zoom

After choosing the **Preview Selection** menu, use the **Image Zoom → Zoom Out** or **Image Zoom → Zoom In** ("D" in the figure above) to achieve the desired image scale. If Zoom In is not available, then the image is at the closest zoom possible for the area. Using the Zoom Out will give a lower resolution (quality) image, however the file size will be reduced. If you use the highest quality (fully zoomed in) option, the file size of the image will be higher and it will take longer to download the image(s).

Save Selection

Select the **Save Selection** menu ("E" in the figure above) to save the selected map area to a single JPG or multiple JPG files. There may be certain restrictions to the size of a single image file, so saving to the multiple files allows one to create a background for a bigger map area. The program automatically creates a folder with a set of the multiple image files to cover the selected background image.

Show Map

The **Show Map** menu ("F" in figure in the figure above) will return to the Bing™ world map to select a different area to be converted to the background image.

Use the [Esc] key to cancel a command. For instance, if you have clicked on the [Color] button in the Map Settings window, use [Esc] to back-up without changing the color.

Map Settings

Use the command **Options→Map-Settings** to open the MAP SETTINGS Window. This window can be used to control the view of the Map View.

Often, it is nice to turn on the Intersection Paths in the Map Settings when coding your networks.

Basic Node Settings

To activate the **NODE** settings, double click on an intersection or select an intersection and press [Enter].

The Node number will establish the order that intersection reports are printed.

Zones can be used to optimize sections of your file; print portions of your file and to set network settings for a section of your file.

Node Number

All intersections and external nodes are assigned a unique node number. used to identify the node in reports and data exported to CORSIM, HCS and UTDF files.

Zone

Synchro allows intersections to be assigned to zones. Zones are useful for analyzing a section of a network. Use zones to keep the timings for some intersections constant while the timings for other intersections are changed.

Node Coordinates

The **NODE** settings allow the X, Y and Z coordinates to be entered exactly. The coordinates of the nodes are used in the layout of the map and the geometry of intersection approaches.

HANDOUT

The X, Y and Z coordinate settings provide a convenient method for moving intersections to exact coordinates. The coordinates are for the center point of the intersection. For traffic engineering purposes, it is good enough to have the coordinates to within 20 feet.

To create an overpass, assign a higher Z coordinate elevation to the nodes of the overpass link. The Z elevation is only used for visual purposes.

Description

The **Description** cell is a convenient location to type notes about the intersection. The information will appear at the bottom of the Intersection Reports.

Default Settings

The following settings have a [**Default**] button available:

- ✓ Network Settings (Synchro)
- ✓ Report Settings (Synchro and SimTraffic)
- ✓ Map Settings (Synchro and SimTraffic)
- ✓ Driver and Vehicle Parameters (SimTraffic)
- ✓ Interval Parameters (SimTraffic)

Some organizations may lock down the application directory. Therefore, the administrator may need to change or deploy the defaults file.

Synchro defaults are stored in the "Defaults.SYN" file. The SimTraffic defaults are stored in the "Defaults.SIM" file. If you are sharing your defaults, be sure to send both files.

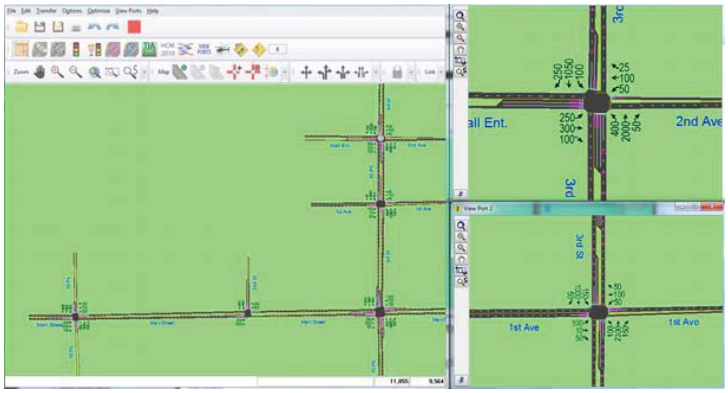
Using the [**Default**] button loads in the defaults for the given dialog, window or view.

The defaults are read from a no intersection file (defaults.syn) in the Trafficware directory. When a user has a file with preferred defaults settings, it can be saved as the "defaults.syn" file and placed in the Trafficware directory (or wherever Synchro is installed). If an organization wants to have standard settings for everyone, they can deploy a defaults.syn to all users. Also see Section page 2-37 for information on default detector settings.

View Ports in Synchro

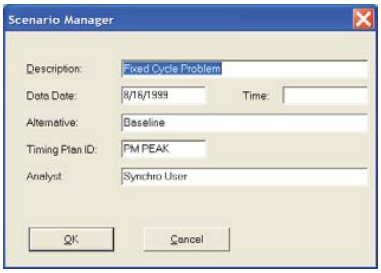
NEW

Users have the ability to create up to four view ports in Synchro.



Scenario Manager Dialog

The Scenario Manager is used to populate the report header and footer information. In the past, updating the Scenario Manager for a new file (scenario) was often overlooked. In Version 8, the Scenario Manager dialog window appears when you save a Synchro project with another name as well as when you create a new Synchro project.



HANDOUT

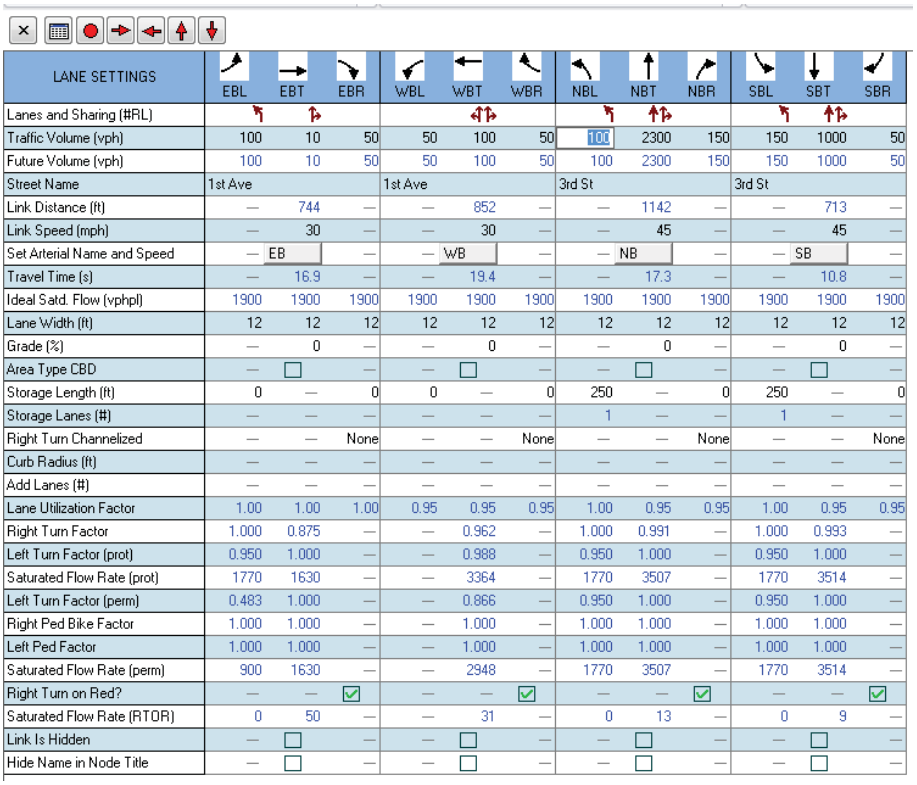
2.3 Lane Settings

From the **MAP** view, click on the desired intersection with the **Right** mouse button and select Lanes.

From anywhere in the program, press [F8] and select the desired intersection from the list.

Then push the ***Lane Settings*** button or the [F3] key.

The **LANE** Settings displays a grid in which you can enter lane and geometric information.



LANE SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	100	10	50	50	100	50	100	2300	150	150	1000	50
Future Volume (vph)	100	10	50	50	100	50	100	2300	150	150	1000	50
Street Name	1st Ave			1st Ave			3rd St			3rd St		
Link Distance (ft)	—	744	—	—	852	—	—	1142	—	—	713	—
Link Speed (mph)	—	30	—	—	30	—	—	45	—	—	45	—
Set Arterial Name and Speed	—	EB	—	—	WB	—	—	NB	—	—	SB	—
Travel Time (s)	—	16.9	—	—	19.4	—	—	17.3	—	—	10.8	—
Ideal Satd. Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	12	12	12	12	12	12	12	12	12
Grade (%)	—	0	—	—	0	—	—	0	—	—	0	—
Area Type CBD	—	☐	—	—	☐	—	—	☐	—	—	☐	—
Storage Length (ft)	0	—	0	0	—	0	250	—	0	250	—	0
Storage Lanes (#)	—	—	—	—	—	—	1	—	—	1	—	—
Right Turn Channelized	—	—	None	—	—	None	—	—	None	—	—	None
Curb Radius (ft)	—	—	—	—	—	—	—	—	—	—	—	—
Add Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Utilization Factor	1.00	1.00	1.00	0.95	0.95	0.95	1.00	0.95	0.95	1.00	0.95	0.95
Right Turn Factor	1.000	0.875	—	—	0.962	—	1.000	0.991	—	1.000	0.993	—
Left Turn Factor (prot)	0.950	1.000	—	—	0.988	—	0.950	1.000	—	0.950	1.000	—
Saturated Flow Rate (prot)	1770	1630	—	—	3364	—	1770	3507	—	1770	3514	—
Left Turn Factor (perm)	0.483	1.000	—	—	0.866	—	0.950	1.000	—	0.950	1.000	—
Right Ped Bike Factor	1.000	1.000	—	—	1.000	—	1.000	1.000	—	1.000	1.000	—
Left Ped Factor	1.000	1.000	—	—	1.000	—	1.000	1.000	—	1.000	1.000	—
Saturated Flow Rate (perm)	900	1630	—	—	2948	—	1770	3507	—	1770	3514	—
Right Turn on Red?	—	—	☑	—	—	☑	—	—	☑	—	—	☑
Saturated Flow Rate (RTOR)	0	50	—	—	31	—	0	13	—	0	9	—
Link Is Hidden	—	☐	—	—	☐	—	—	☐	—	—	☐	—
Hide Name in Node Title	—	☐	—	—	☐	—	—	☐	—	—	☐	—

NEW

Synchro 9 now includes Templates that can be used to populate the approach geometry.

Don't forget to use the keyboard numbers (1-8) to enter lanes to speed up lane entry. The [L] key will add a shared left to a through and the [R] key will add a shared right to a through lane.

Lanes

Under the appropriate picture, enter the number of lanes for that lane group.

For each lane group, enter the number of lanes as a value between 0 and 8, or select the lane configuration from the drop down list.

For the through lane group, specify whether it shares with left or right traffic by pressing [R] or [L] selecting the appropriate configuration from the list.

Changing the Name of the Approach Direction

Take Note

To change the name of an approach direction, right click on the column label of the **LANES**, **VOLUMES**, **TIMINGS** window, or **SIMULATION OPTIONS** settings. Double click on the desired direction name to reassign the direction. To reset the direction to the "natural" map direction, select "Free".

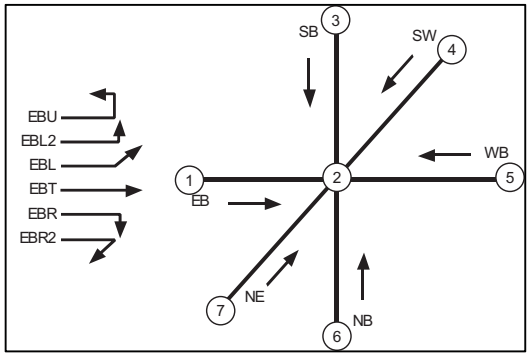
This feature is intended to reclassify diagonal approaches into orthogonal approaches (NB, SB, EB, WB). This feature is not intended to rotate an entire intersection or map. North must always be up on the Map View. (Also see page 2-3, Link Directions.)

HANDOUT

Approach Movements

Synchro will allow 6 movements per approach. This includes 1 through, 1 U-turn, 2 lefts and 2 rights. The through is defined as the opposing direction.

Consider the graphic of the six-leg intersection at the right. Traveling from node 1-2-5 is assigned the EBT direction, 1-2-4 is the EBL, 1-2-3 is the EBL2 (hard left), 1-2-1 is the U-turn, 1-2-6 is the EBR and 1-2-7 is the EBR2 (hard right).



If you do not have two opposing directions that line up (i.e, EB and WB), then there would be no through movement defined. If you want a through movement to be defined, the opposing link must be labeled with the opposing direction. You could change the approach name (as defined above) to create the through movement.

A rule about Synchro and SimTraffic is that any entered volume will be shared with the next available adjacent lane, even if the dropdown lane diagram does not show this.

Assume in the graphic to the left that the EBR and EBR2 are shared with the EBT lane. All shared lanes are coded in the through lane group. However, there is no choice for a shared EBR2 in the lane group diagram. Simply code a volume for the EBR2 and this will be shared with the first adjacent lane.

Street Name

Naming a street will cause its name to appear on the map. If a street has several segments, the name will be placed on a segment long enough to fit the name, or on an external link. To change the size of the street name, see **Options→Map-Settings**.

Use the command [Ctrl]+[U] to open a U-turn column.

Link Distance

Link distances can be used to adjust the length of the link for Synchro only. The calculated link distance is shown in blue. Overridden distances appear as red. To revert to the calculated distance, press [F12] when in the cell.

The link distances are the distance from intersection center point to center point. When determining link distances for queuing analysis, Synchro will subtract 80 feet (24m) from the distance to account for the space inside intersections.

Geodetic coordinates accurate within 20 feet are adequate for traffic modeling purposes.

Changing the Link Distance in the **LANE** settings changes the internal link length. This setting does not change the coordinates of the underlying intersections. Synchro stores the link length independently from the coordinate distances.

It is always best to move the node to the correct location and NOT to over-ride the Link Distance.

Link Speed

The **Link Speed** should be set to the legal safe speed that you expect along the arterial after the traffic signals along the link are optimized. To set a default speed for newly created intersections or change all of the speeds, use the **Options→Network-**Settings command.

Set Arterial Name and Speed

Select a direction button to propagate the name and speed up and down the entire arterial in the selected and opposing direction. For instance, choose the [EB] option will set the street name and speed for the arterial in the eastbound and westbound directions.

Travel Time

Travel Time is recalculated when either the speed or distance fields are changed. The calculated value will appear in blue type. However, you may override this field manually, which will appear in red type. You can force the field to re-calculate based on the speed and distance fields at any time by pressing [F12].

Ideal Saturated Flow

Enter the ideal saturated flow rate for a single lane in this field. Synchro defaults to the HCM default of 1,900 as suggested by the HCM.

The 2010 HCM suggests using an ideal saturated flow rate of 1,750 pc/hr/l for areas with less than 250,000 population.

HANDOUT

Many of the inputs in the LANE window are used to calculate the saturation flow for the subject lane group. The ideal saturation flow is used as the base. Adjustments are then made to reduce or increase the saturation flow of the lane group based on:

- The number of lanes
- The width of the lane
- The percent heavy vehicles
- Grade of the approach
- Parking and busses
- Area type (CBD or othear)
- Lane utilization and movement type (left/right)
- Pedestrians and bicycles

Channelized rights only apply to SimTraffic. Refer to page 2-20 for special notes about channelized rights.

Lane Width

Enter the average lane widths for each lane group in feet (meters). 12 feet (3.6 meters) is the default. The lane width affects the saturated flow rate.

For SimTraffic, Lane width affects the drawing and the Headway Factor that will influence headways and saturated flow rates.

Grade

Enter the percentage grade for each approach. The default is zero percent. The grade affects the saturated flow rate. The grade is the slope for traffic approaching the intersection. Use a negative grade for downhill. In SimTraffic, the grade will change the Headway Factor.

Area Type

Enter "CBD" or "Other" depending on whether the intersection is in a Central Business District or in another type of area. The default is "Other ". The area type affects the saturated flow rate (Synchro) and Headway Factor (SimTraffic).

Storage Length and Lanes

Refer to the Simulation Settings, page 2-29.

Right Turn Channelized

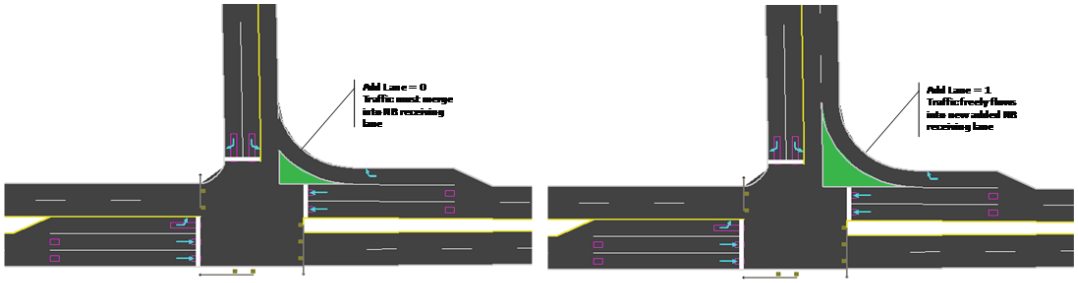
This field is active for the rightmost movement. The choices are None, Yield, Free, Stop and Signal. If this value is changed, it will also be updated for unsignalized analysis. This value is only used for simulation

Curb Radius

Controls the graphics and layout in SimTraffic. It is measured from center point to curb.

Add Lanes

Add Lanes controls how many add lanes are for the right turn movement. Set to zero (0) for a yield or merge. Set to the number of turning lanes for add lanes. The default value is zero (0) for no add lanes.



Link Is Hidden

The LANE SETTINGS screen has a **Link Is Hidden** checkbox for each link (street). If the checkbox is checked, the corresponding link is not visible.

Link Is Hidden	☐
Hide name in node title	☐

Synchro requires a node to have 3 links before it is considered an intersection (allowing signal timing). This **Link Is Hidden** option can be useful for locations where you require the node to be an intersection. The dummy link could be hidden since it will have no lanes or volumes. For example, a mid-block ped crossing, gate or ramp meter could use this option.

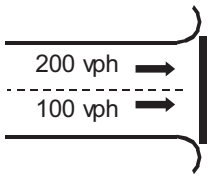
HANDOUT

Hide Street Name in Node Title

The LANE SETTINGS window has a **Hide Name in Node Title** checkbox for each link (street). If the checkbox is checked, the corresponding street name is not used in the node title. The street name will still be visible in the MAP VIEW unless you use the Link Menu command to hide/show the street name.

Lane Utilization Factor

When there is more than one lane in a lane group, the traffic will not use all the lanes equally. The Lane Utilization Factor affects the Saturated Flow Rate (**changing this will not impact SimTraffic**). This value can be overridden. If the actual per lane volumes are know, the Lane Utilization factor can be calculated per the following example:



$$fLU = \frac{\text{Total App. Vol.}}{(\text{No. of Lanes}) \times (\text{High Lane Vol.})} = \frac{(100 + 200)}{(2 \times 200)} = 0.75$$

The lane utilization factor can have a large impact on the results. If vehicles do not use the lanes equally, a field study should be performed to determine the fLU.

This will not change your SimTraffic analysis.

Right Turn Factors

The Right Turn Factor fields are calculated but can be overridden. The right turn factors represent how much the interference from right turning traffic reduces the saturated flow rate (turning speed is used for SimTraffic, see page).

Left Turn Factors

The Left Turn Factors are calculated but can be overridden. The left turn factors represent how much the interference from left turning traffic reduces the saturated flow rate (turning speed is used for SimTraffic).

Synchro implements the 2000 HCM model for permitted left turn factors.

Saturated Flow Rates

The saturated flow rates are the actual maximum flow rate for this lane group after adjusting for all of the interference factors. The saturated flow rates represent the number of lanes multiplied by the Ideal Saturated Flow Rate and interference factors due to heavy vehicles, buses, parking maneuvers, lane widths, area type, grade, and turning movements. The HCM explains all of these calculations in detail.

The Saturated Flow rates are used in capacity and delay calculations, and for optimization calculations. The Saturated Flow rates are not used by SimTraffic. The **Headway Factor** is used to calculate an equivalent flow for use in the simulation.

These fields are calculated but can be overridden.

Right Ped Bike Factor

This factor is calculated based on the number of pedestrians and bicycles are crossing the right turn movement. The factor takes into account the amount of green time for the pedestrians and the bicycles as well as the number of downstream receiving lanes.

Left Ped Factor

This factor is calculated based on the number of pedestrians and bicycles are crossing permitted left turn movements. The factor takes into account the amount of green time for the pedestrians and vehicles, the amount of oncoming traffic and the number of downstream receiving lanes.

HANDOUT

Right Turn on Red

This field is used to specify whether Right Turns on Red (RTOR) are allowed. This field can also be used to allow Left Turns on Red from a one-way to a one-way.

Synchro now fully models Right Turns on Red. Synchro automatically calculates a Saturated Flow Rate for RTOR and applies this flow rate to movements when they are red.

This field is also used when modeling in SimTraffic and CORSIM.

Saturation Flow Rate (RTOR)

The sRTOR value is NOT the volume that will make the RTOR. The volume of RTOR (vRTOR) can be calculated as:

vRTOR = sRTOR x (1-g/C)

Synchro automatically calculates saturation flow rate for Right Turns on Red. This saturation flow rate is applied to a movement whenever the movement has a red signal. This calculation is also made for Left Turns on Red for crossing one-way streets.

The calculation of the RTOR Saturation Flow Rate is quite complex and is based on the signal timing, the volumes of the subject approach, and the volumes of any merging approaches.

It is possible to override the RTOR saturation flow rate to a measured value or hand calculated value. Overriding RTOR sat flow is not recommended because overridden values will not be updated when the volumes or signal timings change. The RTOR Sat Flow is very sensitive to changes in volumes and timings.

sRTOR = Minimum(sRTOR1, sRTOR2) = RTOR Saturation Flow Rate

sRTOR1 = saturation flow rate based on gaps in merging traffic

sRTOR2 = limit to saturation flow rate based on through traffic blocking access to stop bar

HANDOUT

2.4 Volume Settings

From the **MAP** view, click on the desired intersection with the **Right** mouse button and select Volumes.

From anywhere in the program, press [F8] and select the desired intersection from the list. Then push the ***Volume*** *Settings* button or the [F4] key.

The **VOLUME** Settings displays a grid in which you can enter traffic volume information.

VOLUME SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	100	10	50	50	100	50	100	2300	150	150	1000	50
Development Volume (vph)	0	0	0	0	0	0	0	0	0	0	0	0
Combined Volume (vph)	100	10	50	50	100	50	100	2300	150	150	1000	50
Future Volume (vph)	100	10	50	50	100	50	100	2300	150	150	1000	50
Conflicting Peds. (#/hr)	0	—	0	0	—	0	0	—	0	0	—	0
Conflicting Bicycles (#/hr)	—	—	0	—	—	0	—	—	0	—	—	0
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Growth Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Adjusted Flow (vph)	100	10	50	50	100	50	100	2300	150	150	1000	50
Heavy Vehicles (%)	2	2	2	2	2	2	2	2	2	2	2	2
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Adj. Parking Lane?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Parking Maneuvers (#/hr)	—	—	—	—	—	—	—	—	—	—	—	—
Traffic from mid-block (%)	—	0	—	—	0	—	—	0	—	—	0	—
Link OD Volumes	—	—	—	—	—	—	—	NB	—	—	SB	—
Traffic in shared lane (%)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Group Flow (vph)	100	60	0	0	200	0	100	2450	0	150	1050	0

Keep in mind that the volumes in this window are hourly volumes. If you simulate less than 60 minutes in SimTraffic, the equivalent proportion of vehicles will be modeled. Before gathering results from SimTraffic, you will probably want to simulate a 60 minute period. Special cases may require simulations of more or less time.

Traffic Volumes

In the appropriate cell, enter the hourly traffic volumes for each movement. Enter this number as vehicles per hour.

Only enter traffic volumes for the targeted design hour. To develop timing plans for other times of the day, you could use the UTDF Volume table (see page 4-23, Database Access and UTDF). SimTraffic will simulate this volume based on the interval times you set-up (see page 4-28). If you use an interval of 10 minutes in SimTraffic, approximately 1/6 of the hourly volume will be simulated.

Conflicting Bicycles do not need to be entered for left turns. It is assumed that they will clear during the queue clearance time for vehicles.

Conflicting Pedestrians

Enter the number of pedestrians, per hour, that conflict with the right turn movement during the permitted phase. This number affects the Right Turn Factor and the Saturated Flow Rate shown in the **LANE window** for the permitted right turns. SimTraffic will simulate the equivalent number of peds.

Conflicting Bicycles

Enter the number of through bicycles that conflict with right turns. If bicycles cross the right turn traffic ahead of the intersection, enter 0. This input will affect the Right Ped-Bike factor in the **LANE** settings.

Peak Hour Factor

The traffic volumes are divided by the Peak Hour Factor (PHF) to determine the traffic flow rate during the busiest 15-minute period during the hour. Also see page 4-30, Using the Peak Hour Factor Adjustment in SimTraffic.

HANDOUT

Synchro allows you to change the Analysis Period, T. Traditional analysis (HCM based) has the peak 15 minute period converted to hourly volumes with the PHF. If the analysis period is changed to a value greater than 15, the PHF will be changed to 1.0 and is not editable. The Analysis Period is changed within the Network Settings.

From the HCM:

"The bus blockage adjustment factor, fbb, accounts for the impacts of local transit buses that stop to discharge or pick up passengers at a near-side or far-side bus stop within 250 ft of the stop line (upstream or down-stream)."

Synchro includes a show Volume Balancing button on the Map View. Click on the [VB] button to display the unbalance of traffic volumes between intersections. This can be used in conjunction with volume diagrams for quick editing adjustments.

Growth Factor

The growth factor can be used to adjust the traffic volumes. The raw volume data is multiplied by the growth factor when calculating Adjusted volumes and Lane Group volumes. The growth factor can be 0.5 to 3.0. By default, SimTraffic will use the growth factor that is input. This can be modified in the SimTraffic Intervals window.

Heavy Vehicles

Enter the percentage of vehicles that are trucks or buses for this movement. This value affects the saturated flow rate shown in the **LANE window**. The default for this field is 2%.

In SimTraffic, the heavy vehicle fleet volume for each movement is equal to the volume multiplied by the Heavy Vehicle percentage. The light vehicle fleet volume is equal to the remaining volume. Heavy Vehicle fleet traffic will be assigned one of the 4 truck types or a bus type. The Light Vehicle fleet traffic will be assigned to a car or carpool vehicle type. Also see page **4-31**, Vehicle Parameters.

Bus Blockages

Enter the number of busses per hour that stop and actually block traffic. This value affects the saturated flow rate shown in the **LANE window**. The default for this field is zero busses per hour. Enter bus blockages for each lane group that is affected by the blockage.

Adjacent Parking Lane, Parking Maneuvers

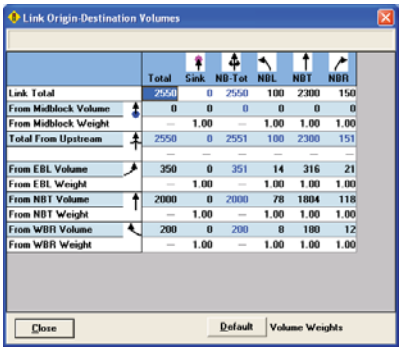
If there is on street parking for this approach, enter "Yes" for Adjacent Parking Lane and the number of maneuvers per hour for Parking Maneuvers. This value affects the saturated flow rate shown in the **LANE window**. The default for this field is "No" adjacent parking lane. Enter parking maneuvers for each lane group that is affected by the blockage. See the HCM for additional information.

This value will change the Headway Factor, thereby reducing the saturation flow in SimTraffic. You will not see vehicles making parking maneuvers in SimTraffic.

Traffic From Mid-block

The Traffic From Mid-block field tells Synchro what proportion of the traffic came from driveways and unsignalized intersections, not the next signalized intersection. A value of 50 indicates that 50% of the traffic is from driveways.

Also refer to the topic "Traffic from Mid-Block" in the Synchro Studio Users Guide for details on how Synchro handles unbalanced flow between intersections.



Link O-D Volumes

Link O-D Volumes allows detailed control over the origin and destination of two adjacent intersections. Link O-D Volumes can be used to reduce or eliminate certain turn combinations. The most common use is to prevent vehicles from turning left twice at a freeway or wide median arterial.

The **LINK ORIGIN-DESTINATION VOLUMES** window displays Movement Weighting Factors that control how volume is allocated between input and output volumes.

If you change one of the weighting factors, the other volumes will be dynamically updated to balance.

HANDOUT

Adjusted Flow

The Adjusted Flow (vph) is the entered volume modified by the Peak Hour Factor and Growth Factor (Adjusted Flow = Input Volume/PHF x Growth Factor).

Traffic in Shared Lane

Traffic volumes assigned to exclusive and shared lane are proportioned to each lane as follows.

Vehicles are counted as passenger car equivalents (PCE) as follows

Throughs: 1

Rights: 1.18

Protected Lefts: 1.05

Permitted Lefts: 1 / [0.95 * (900 – vOp)/900], (max 6.67)

Permitted plus protected Lefts: 2/ [0.95 + 0.95 * (900 – vOp)/900], (max 1.82)

vOp = through volume opposed.

Traffic is assigned so that PCEs are balanced between lanes. The assignment of traffic to the shared lane is between 10% and 90% of the turning traffic.

This simplified left turn factor removes the interdependence of lane assignments from the permitted left turn factor (see the Synchro Studio User Guide) calculation. As a practical matter, the need for a permitted left-turn factor is somewhat nullified by this lane assignment procedure.

Traffic in Shared Lane can be overridden to control lane assignment in Synchro. **This setting will not have any impact on SimTraffic simulations.** In simulations, individual vehicles choose their lanes based on lane change algorithms.

Lane Group Flow

The Lane Group Flow shows how volumes are assigned to lane groups.

If there are no turning lanes, the turning volume is assigned to the through lane group. The shared lanes are part of the through lane group and the exclusive lanes are part of those movements' lane groups.

HANDOUT

2.5 Timing Settings Input

From the **Map View**, click on the desired intersection with the **Right** mouse button and select Timing.

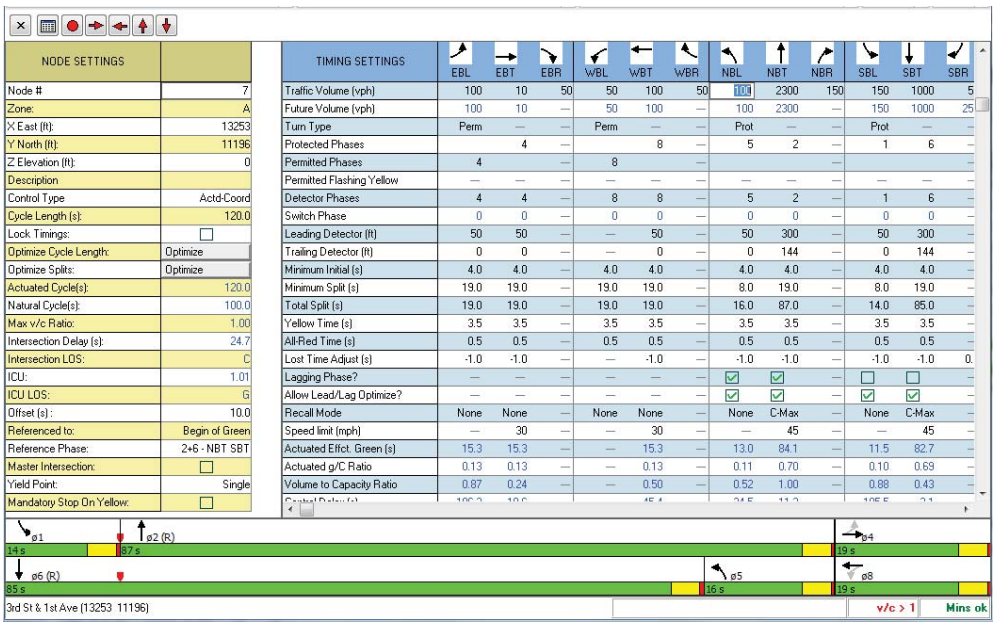
From anywhere in the program, press [F8] and select the desired intersection from the list.

Then push the ***Timing** Settings* button or the [F5] key.

The TIMING Settings includes the most complex data entry items.

The **TIMING** settings are displayed with information about the timing and phasing.

In the **TIMING** settings, there is a column for every vehicle movement and every vehicle movement can have multiple phases. There is also a column for a pedestrian only phase. To make a pedestrian only phase, assign a phase number to this column.



NODE SETTINGS	
Node #	7
Zone:	A
X East (ft):	13253
Y North (ft):	11196
Z Elevation (ft):	0
Description	
Control Type	Actd-Coord
Cycle Length (s):	120.0
Lock Timings:	☐
Optimize Cycle Length:	Optimize
Optimize Splits:	Optimize
Actuated Cycle(s):	120.0
Natural Cycle(s):	100.0
Max v/c Ratio:	1.00
Intersection Delay (s):	24.7
Intersection LOS:	C
ICU:	1.01
ICU LOS:	G
Offset (s):	10.0
Referenced to:	Begin of Green
Reference Phase:	2+6 - NBT SBT
Master Intersection:	☐
Yield Point:	Single
Mandatory Stop On Yellow:	☐

TIMING SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Traffic Volume (vph)	100	10	50	50	100	50	100	2300	150	150	1000	5
Future Volume (vph)	100	10	—	50	100	—	100	2300	—	150	1000	25
Turn Type	Perm	—	—	Perm	—	—	Prot	—	—	Prot	—	—
Protected Phases		4	—		8	—	5	2	—	1	6	—
Permitted Phases	4		—	8		—			—			—
Permitted Flashing Yellow	—	—	—	—	—	—	—	—	—	—	—	—
Detector Phases	4	4	—	8	8	—	5	2	—	1	6	—
Switch Phase	0	0	—	0	0	—	0	0	—	0	0	—
Leading Detector (ft)	50	50	—	—	50	—	50	300	—	50	300	—
Trailing Detector (ft)	0	0	—	—	0	—	0	144	—	0	144	—
Minimum Initial (s)	4.0	4.0	—	4.0	4.0	—	4.0	4.0	—	4.0	4.0	—
Minimum Split (s)	19.0	19.0	—	19.0	19.0	—	8.0	19.0	—	8.0	19.0	—
Total Split (s)	19.0	19.0	—	19.0	19.0	—	16.0	87.0	—	14.0	85.0	—
Yellow Time (s)	3.5	3.5	—	3.5	3.5	—	3.5	3.5	—	3.5	3.5	—
All-Red Time (s)	0.5	0.5	—	0.5	0.5	—	0.5	0.5	—	0.5	0.5	—
Lost Time Adjust (s)	-1.0	-1.0	—	—	-1.0	—	-1.0	-1.0	—	-1.0	-1.0	0.
Lagging Phase?	—	—	—	—	—	—	☑	☑	—	☐	☐	—
Allow Lead/Lag Optimize?	—	—	—	—	—	—	☑	☑	—	☑	☑	—
Recall Mode	None	None	—	None	None	—	None	C-Max	—	None	C-Max	—
Speed limit (mph)	—	30	—	—	30	—	—	45	—	—	45	—
Actuated Effct. Green (s)	15.3	15.3	—	—	15.3	—	13.0	84.1	—	11.5	82.7	—
Actuated g/C Ratio	0.13	0.13	—	—	0.13	—	0.11	0.70	—	0.10	0.69	—
Volume to Capacity Ratio	0.87	0.24	—	—	0.50	—	0.52	1.00	—	0.88	0.43	—

Lanes and Sharing

Refer to the Lane settings, page 2-10.

Traffic Volume

Refer to the Volume settings, page 2-15.

Phase Templates

Phase templates allow phase numbers to be set automatically.

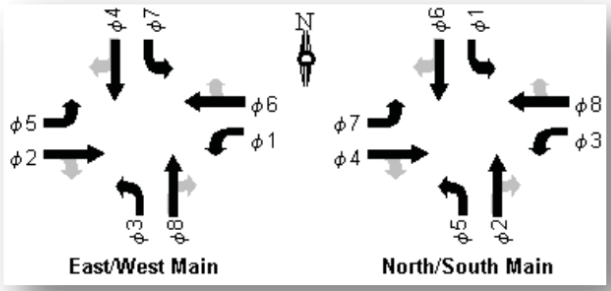
Phase numbers are the labels assigned to the individual movements around the intersection. For an eight phase dual ring controller, it is common to assign the main street through movements as phases 2 and 6. Also, it is common to use odd numbers for left turn signals and the even numbers for through signals. A rule of thumb is that the sum of the through movement and the adjacent left turn is equal to seven or eleven.

To set phases for an east-west arterial use the menu command **Options→ Phase-Templates→ Intersection-to-East-West**.

To set phases for a north-south arterial use the menu command **Options→ Phase-Templates→ Intersection-to-North-South**. Phases 2 and 6 are normally used for the main street. Thus, two templates are provided for each type of arterial.

To edit the phase templates use the menu command **Options→ Phase-Templates→ Edit-Template-Phases**.

HANDOUT



Turn Type

The turn type row allows for the easy setting of Left turn and Right turn treatments.

Using the Turn Type settings makes it easy to set phase numbers. If you prefer, the phase numbers can be set also.

Left Turn Type

The eight types of left turn treatment are:

1. **Permitted**: There is no protected left turn signal, the left is allowed to operate with the adjacent through. Left turns must yield to oncoming traffic.
2. **Protected**: There is a left turn signal. Left turns are *only* allowed during the left turn phase.
3. **Permitted + Protected**: There is a left turn signal and traffic is also allowed to turn left on a green ball when there is a gap in oncoming traffic. With permitted plus protected phasing, it is common to use a signal with five heads for the left turn lane.
4. **Split**: Left and through traffic share a single protected phase. This type of phasing is commonly used if a lane is shared between left and through traffic. Split Phasing is also used if there might be a problem with-head on collisions between oncoming left turns. If there is a through approach, either both or neither of the two approaches must use Split phasing. If there is no through approach, such as at a T intersection, then the left turn treatment should always be split.
5. **Dallas Permitted**: A special type of phasing developed in the Dallas, TX area. The left turn lane has its own signal head. The left signal head is louvered to make it invisible from adjacent lanes. The ball in the left lane displays the same phase displayed to oncoming through traffic. This configuration eliminated the lagging left turn trap problem.
6. **Dallas Permitted plus Protected**: A special type of phasing developed in the Dallas, Texas area. The left turn lane has its own signal head. The left signal head is louvered to make it invisible from adjacent lanes. The ball in the left lane displays the same phase displayed to oncoming through traffic. This configuration eliminated the lagging left turn trap problem.
7. **NA**: No phase selected. Left turns are prohibited.
8. **Custom**: A non-standard left turn phase combination is selected.

The turn type "permitted plus protected" does NOT indicate the order of the phase. The left turn may be a lead or a lag, and depends on the Lead/Lag setting in the PHASING settings.

A research report NCHRP 3-54 studied the best traffic signal display for protected/permitted left turn control. The resulting recommendation is to use a four section signal head with a flashing yellow arrow for the permitted left turn interval. This type of arrangement allows for the safe implementation of lead-lag permitted plus protected phasing. There is no need for special louvers or positioning of the signal heads.

Extensive information can be found by doing a web search on Flashing Yellow Arrow.

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Right Turn Type

If there is right turn traffic, there is an option for the right turn treatment. There are eight choices.

1. **Perm:** Permitted, right turns go on green ball but yield to pedestrians.
2. **Prot**: Protected, right turns go on green ball and are protected from pedestrians.
3. **Over**: Overlap, right turns go on a compatible left turn phase.

   Overlap should not be used as a substitute for Right Turn on Red. See **Right Turn on Red** for guidance on which type to use. Overlap should only be used if the movement actually has a green arrow during the overlapping phase.

4. **Pm+Ov**: Permitted plus Overlap, allows both if applicable.
5. **Pt+Ov**: Protected plus Overlap, allows both if applicable.
6. **Free:** Free turn with acceleration lane, must still yield to pedestrians. For a free right turn, code the permitted phase as F or Free.
7. Free should not be used as a substitute for Right Turn on Red. See **Right Turn on Red** for guidance on which type to use. Free should only be used if the movement has an acceleration lane downstream.
8. **NA**: No right turn phase entered. Right turns are prohibited
9. **Custom:** Non-standard right turn phases are entered.

Synchro will automatically enter the phase numbers based on the phase template and turn treatment you have selected. For instance, if you are using the East-West template and enter 'Prot' for the EBL, Synchro will place a phase 5 in the EBL Protected Phase row.

Protected and Permitted Phases

The Phase rows are used to assign one or more phases for each movement. During protected phases, traffic can move without conflict. During permitted phases, left turning traffic must yield to oncoming traffic and right turn traffic must yield to pedestrians. Conflicting phases have the phase number shown in **red**. Permitted Left Turns do not conflict with movements bound for the same link. Permitted through movements do not conflict with left turns bound for the same link.

Most signals in North America use dual ring controllers, which have two phases active at once. For further details on dual ring control, please refer to the Synchro Help file, Background Timing chapter, and subtopic on Ring Structure.

Notes on Channelized Rights

The channelized right settings (see page 2-12) do not have any impact on your Synchro analysis and are intended for SimTraffic modeling. However, the following could be considered for the given channelized right turn code.

- ✓ Yield: assign the right turn the same phase as the adjacent through and any non-conflicting left that exists. Set the RTOR (see page 2-14) equal to Yes.
- ✓ Stop: same suggestions as for the Yield control
- ✓ Free: Set the phase to Free
- ✓ Signal: Set the appropriate phase number desired since the movement is controlled by the signal.

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Controller Type

Use the Controller Type field to indicate what type of controller you are using. The choices are:

Pretimed: This signal has no actuation. All phases are set to Maximum recall.

SemiAct-Uncoordinated: The main street phases have maximum recall and will always show to their maximum green time. Side street phases may be actuated and can be skipped or gap-out early. Signals with semi-actuated operation have a variable cycle length and are not coordinated.

Actuated-Uncoordinated: No phases have maximum recall. All phases are actuated and can be skipped or gap-out early.

Actuated-Coordinated: With Coordinated operation, the controller operates on a fixed cycle. Side street phases are actuated and can be skipped or gap-out. Any unused time is added to the main street phases.

Unsignalized: With this setting the intersection has no signal at all. Unsignalized intersections have stop signs and yield signs to control traffic and is based on the 2000 HCM.

Roundabouts: Synchro models single lane traffic circles or roundabouts using the HCM 2000 method. Go to the HCM 2010 Settings for the 2010 Roundabout methods.

Additional details can be found on controller types in the Signal Timing Background book found in the Trafficware directory. See the subtopics on Controller Types.

SimTraffic will model a roundabout, including multi-lane roundabouts. The modeling of roundabouts in Synchro is limited to giving a v/c ratio for a single lane roundabout. This is to mimic the methods of the 2000 HCM.

Sign Control

If Control Type is set to Unsignalized, this intersection becomes unsignalized and the third row is Sign Control.

Detector and Switch Phases

Detectors in the subject lane group will call and/or extend the **Detector Phases**. The function of the detector is set in the **DETECTORS** settings in the **Detector Type** row. Only one phase number can be entered for the Detector Phase.

The **Switch Phase** is a secondary phase that extends the entered phase when it is green. This setting does not place a call and does not call the primary Detector Phase when the entered switch phase is green.

This setting can be used for the permitted phase of a permitted plus protected left turn. Do not use with a lagging left turn because the protected left will not get called while the permitted phase is green. The default for permitted plus protected is to have the Detector Phase equal to the Protected Phase and Switch Phase set to none.

Cycle Length

The **Cycle Length** is the amount of time it takes a signal to go through its entire sequence once and return to the same place.

<u>Increase Cycle and Split Times</u>

In previous versions of Synchro, the Cycle was limited to 900 seconds and the Maximum Split to 840 seconds. In some instances, a long cycle can be useful to model dummy intersections that can stop traffic for an extended period of time. The **Cycle Length** in the NODE SETTINGS and the **Maximum Split** in the PHASE SETTINGS may now have values up to 3000 sec (50 min). The Cycle Length should not exceed 3000 seconds.

Two examples for using this would be a draw bridge or rail crossing. At the location of the stop, create a dummy intersection (create a T-intersection). Keep in mind that this dummy link can be hidden. Then enter a phase for the main street (say phase 1) and a Hold phase.

Splits for phases within a ring are not required to add up. Synchro will extend a phase to make the rings equal. This extended split is shown in gray on the Splits and Phasing diagram.

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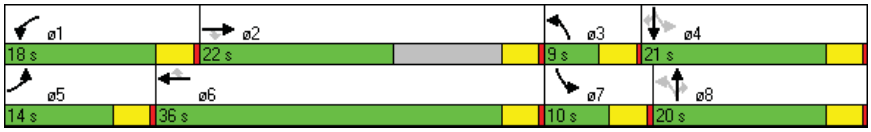
Total Split

The Total Split is the current split time, given in seconds. It is the amount of green, yellow, and all-red time assigned for each phase. When multiple phases are used for a movement, the Total Split is the sum of all phases. The splits for the intersection can be calculated automatically by selecting the **Optimize→Intersection-Splits,** command from the menu.

Splits and Phasing Diagram



The Splits and Phasing diagram is shown at the bottom of the **TIMING** Settings. It is a graphical representation of the current splits and phasing and can be used to adjust the splits. To adjust the splits with the mouse, move the mouse to the right side of a yellow + all red band on the current Splits and Phasing diagram. Hold down the left mouse button and move the mouse right or left to adjust the split.

Next to the movement diagram is a phase number identified with the phase symbol (ø) and inside the green band is the split time in seconds. For the diagram above, the southbound left is ø7 and has a 10s split. Remember that the split time includes the Yellow plus All Red time.

Be sure to choose the offset reference style to match your controller type. If not, this could cause problems when entering the data into the controller. Delays may be higher simply because greens don't occur as expected in Synchro.

Synchro will optimize the offsets (discussed later), but the end user must ensure that this data is properly input into the controller.

Lock Timings

The Lock Timings field is used to prevent the timing from changing. To preserve the timing for one or more intersections, put an X in this field for each of the intersections. If you optimize the network, these intersections' timing plans will not change, but the other intersections will be optimized around them.

Offset Settings

The settings in the Offset Settings box determine to which phase the offset is referenced and the value of the Current Offset. Each intersection is given one offset that can be referenced to any part of any phase. The offset value represents the amount of time after the master intersection when the reference point for this phase occurs.

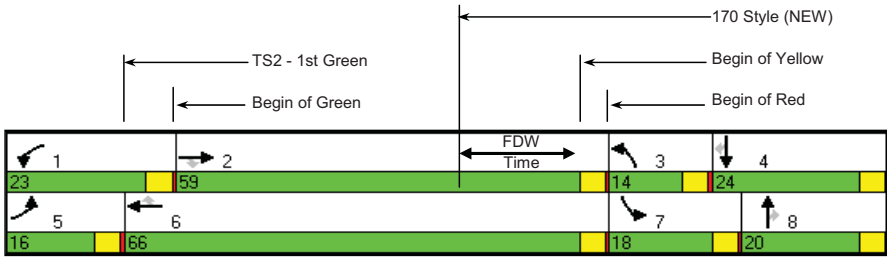
Reference Phase

Select the phase(s) to reference offsets from. This is usually the phase for the main street.

Offset Referenced To

Select the point you wish to have offsets referenced to. The graphic below shows the offset reference points for

Synchro 5 and earlier used Single Yield points, as compared to flexible and multiple. For most analysis situations, Single Yield points can be used. This topic is quite advanced, and will be discussed in more detail in the Level II class. You can also refer to the Synchro Help topic on Offsets for a detailed description.



HANDOUT

Current Offset

The Current Offset for the intersection, in seconds, is the amount of time the reference phase begins (or ends) after the master intersection.

Yield Points

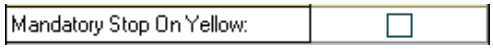
The Yield Point affects when the Coordinated Phases will "yield" to side street phases. This setting affects whether there is a single yield point for all phases; or multiple yield points.

Master Intersection

The Master Intersection always has an offset of zero. In Synchro there is zero or one master intersection for each compatible cycle length used in the network.

Mandatory Stop on Yellow

Traditionally, SimTraffic will allow at least two vehicles to proceed during a signal phase, even if the Total Split is set to 3 seconds. In some instances, it is desirable to create a dummy intersection to meter traffic (i.e., allow 1 vehicle to proceeds every X seconds). This could be useful for modeling security gates, ramp meters, etc.



To do this, check the **Mandatory Stop on Yellow** at the bottom of the NODE SETTINGS. This will allow only one simulated vehicle to pass through a short green signal. No sneaker vehicles will be allowed during the yellow interval.

A master intersection is not required. If you do not specify a master intersection, the offset will be referenced to an arbitrary time line.

Pedestrian and Hold Phases

The far right columns allow an entry of pedestrian only or phase hold. If there is a phase dedicated solely for pedestrians, set the phase number for this column to a valid phase (often an even number larger than 8, such as 10). This is a phase where all vehicle movements are red and pedestrians can walk anywhere in the intersection. Set the phase number to blank to remove the pedestrian phase.

Lost Time Adjustment

Total lost time is calculated as startup lost time plus yellow plus all red, as shown below.

tL = Yi + L1 – e = Total Lost Time

Yi = Yellow plus All-Red Time

L1 = startup lost time = 2.5 seconds by default

e = Extension of effective green = 2.5 seconds by default

The Lost Time Adjustment is the startup lost time minus extension of effective green. The default for startup lost time and extension of effective green is 2.5 seconds, so the Lost Time Adjustment defaults to zero. The extension of the effective green is time vehicles continue to enter after yellow interval begins.

tLA = L1 – e = Lost Time Adjustment

tL = Yi + tLA

Sign Control

If Control Type is set to Unsignalized, this intersection becomes unsignalized and the third row is Sign Control.

There are three options are Free, Yield or Stop.

Note: These Median Type and Median Width fields are only used for 2000 HCM Unsignalized analysis to perform unsignalized analysis with two-stage gap acceptance. SimTraffic does not use the median type or width. SimTraffic 6 is not able to model two-stage gap acceptance or medians at this time.

HANDOUT

Median Type

Enter the type of median that this link CROSSES. It is not the median for the link itself.

Median Width

This row appears in the **SIGNING** window for unsignalized intersections.

This field is active when a Raised or TWLTL is specified for the **Median Type**. Enter the number of vehicles that can be stored in the median. Do not enter the distance of the median width.

Right Turn Channelized

This row appears in the **SIGNING** window for unsignalized intersections.

This field is active for the rightmost movement. Enter yield or free if this movement has a triangular island and yields or merges with oncoming left turn traffic. One or more right turns must be selected.

Synchro 8.0 now provides full modeling of the 2010 HCM methods. Enter Roundabout for Control Type and then choose the "HCM 2010" button.

Roundabout Radius

Inside Radius, Outside Radius control the size of the roundabout. 900' is the maximum. This information is only used by SimTraffic.

Roundabout Lanes

Roundabout number (#) of Lanes is where to set the number of internal lanes within the roundabout, up to 4 lanes. This information is only used by SimTraffic.

Roundabout Speed

Roundabout Speed Limit is the internal speed of vehicles within the roundabout. This information is only used by SimTraffic.

Max Exit Lanes

Two Lane Exit controls how many of the internal lanes exit for the subject approach. This information is only used by SimTraffic.

HANDOUT

2.6 Phasing Settings Input

From the **Map View**, click on the desired intersection with the **Right** mouse button and select Phasing.

From anywhere in the program, press [F8] and select the desired intersection from the list. Then push the ***Phasing*** *Settings* button or the [F6] key.

The **PHASING** settings are displayed with information about the phase settings.

In the **PHASING** screen, there is a column for each phase. If there is no left turn phase, there is no column for left turns.

NODE SETTINGS	
Node #	7
Zone:	A
X East (ft):	13253
Y North (ft):	11196
Z Elevation (ft):	0
Description	
Control Type	Actd-Coord
Cycle Length (s):	120.0
Lock Timings:	☐
Optimize Cycle Length:	Optimize
Optimize Splits:	Optimize
Actuated Cycle 90th (s):	120.0
Actuated Cycle 70th (s):	120.0
Actuated Cycle 50th (s):	120.0
Actuated Cycle 30th (s):	120.0
Actuated Cycle 10th (s):	120.0
Natural Cycle(s):	100.0
Max v/c Ratio:	1.00
Intersection Delay (s):	24.7
Intersection LOS:	C
ICU:	1.01
ICU LOS:	G
Offset (s) :	10.0
Referenced to:	Begin of Green
Reference Phase:	2+6 - NBT SBT

PHASING SETTINGS	1-SBL	2-NBT	4-EBTL	5-NBL	6-SBT	8-WBTL
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0	4.0
Minimum Split (s)	8.0	19.0	19.0	8.0	19.0	19.0
Maximum Split (s)	14.0	87.0	19.0	16.0	85.0	19.0
Yellow Time (s)	3.5	3.5	3.5	3.5	3.5	3.5
All-Red Time (s)	0.5	0.5	0.5	0.5	0.5	0.5
Lagging Phase?	☐	☑	—	☑	☐	—
Allow Lead/Lag Optimize?	☑	☑	—	☑	☑	—
Optimize Phs Weights - Delays	1.0	1.0	1.0	1.0	1.0	1.0
Vehicle Extension (s)	3.0	3.0	3.0	3.0	3.0	3.0
Minimum Gap (s)	3.0	3.0	3.0	3.0	3.0	3.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	C-Max	None	None	C-Max	None
Pedestrian Phase	☐	☑	☑	☐	☑	☑
Walk Time (s)	—	5.0	5.0	—	5.0	5.0
Flash Dont Walk (s)	—	10.0	10.0	—	10.0	10.0
Pedestrian Calls (#/hr)	—	0	0	—	0	0
Dual Entry?	☐	☑	☑	☐	☑	☑
Fixed Force Off?	☑	☑	☑	☑	☑	☑
90th %ile Green Time (s)	10 mx	83 cd	15 mx	12 mx	81 cd	15 mx
70th %ile Green Time (s)	10 mx	83 cd	15 mx	12 mx	81 cd	15 hd
50th %ile Green Time (s)	10 mx	83 cd	15 mx	12 mx	81 cd	15 hd
30th %ile Green Time (s)	10 mx	83 cd	15 mx	12 hd	81 cd	15 hd
10th %ile Green Time (s)	13 gp	84 cd	12 gp	12 hd	84 cd	12 hd

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Minimum Initial

This field is the minimum initial green time for a phase. This is the shortest time that the phase can show green. A typical value would be 4 seconds. This value is also called **minimum green** by some controllers.

Keep in mind that you can set your own Network defaults for some Phasing parameters. These defaults can be updated in your Defaults.syn file located in your Trafficware directory. See page 2-9 for additional details.

Minimum Split

The Minimum Split is the shortest amount of time allowed for this phase.

The Minimum Split is only used for Optimizations and not used in calculation. This is the shortest amount of time that will be allowed for this split when an optimization is performed. It is a user defined parameter. This could be considered the minimum Maximum Split.

The Minimum Split is *only* used for Optimizations and not used in calculation. This is the shortest amount of time that will be allowed for this split when an optimization is performed. It is a user defined parameter. This could be considered the minimum Maximum Split.

The minimum split must at least be long enough to accommodate the Minimum Initial interval plus the yellow and all red time. When Synchro automatically assigns splits, it will make sure all splits are greater than or equal to their minimum splits. (This assumes the cycle length is long enough to accommodate all splits.)

If the Minimum Split shown is red, it indicates a minimum error. The Minimum Split must be greater or equal to the Minimum Initial plus clearance time (Y + AR). If this phase has a

HANDOUT

For actuated movements, the Maximum Green may not be experienced. If the volume is low, a phase may "gap-out" and allow other phases to begin earlier. Synchro fully models actuated movements, so don't be fooled into thinking that the Maximum Green you have entered is the actual time allocated to a movement. Review the Percentile Green times and the Actuated Effective Green times.

Review:
A ring is a term that is used to describe a series of conflicting phases that occur in an established order. Phasing in any one ring cannot operate together.

A barrier (compatibility line) is a reference point in the preferred sequence of a multi-ring controller unit at which all rings are interlocked. Barriers assure there will be no concurrent selection and timing of conflicting phases for traffic movements in different rings.

If the Allow Lead/Lag setting is set to "Yes", Synchro may set some phases to lagging during the network cycle length OR network offset optimization. If you do not want a left phase to lag, be sure you set this setting to "Fixed".

Review the topic on left turn trapping in the Signal Timing Background PDF document in the Trafficware directory. You can find this topic by doing a search on the word 'trap'.

HANDOUT

pedestrian phase, the Minimum Split must be greater or equal to the sum of the Walk time, the Flashing Don't Walk time, the Yellow time and the All-Red time.

Maximum Split

The Maximum Split is the current split time, given in seconds. It is the amount of green, yellow, and all-red time assigned for each phase.

The Maximum Green time would be the Maximum Split minus the Yellow and All-Red.

Yellow Time

Yellow Time is the amount of time for the yellow interval. Normally, this value should be set to between 3 and 5 seconds, depending on the approach speed, the cross street width, and local standards.

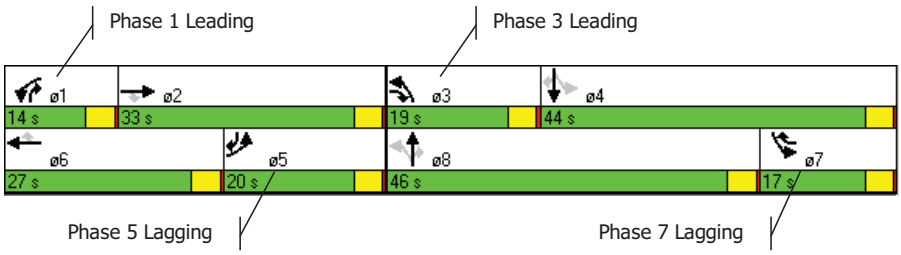
All Red Time

All Red Time is the amount of time for the all red interval that follows the yellow interval.

Phase Lagging

The first two phases within a ring-barrier sequence are considered phase partners. The 3rd and 4th phases within a ring-barrier sequence if used are also phase partners. Phase Lagging is used to swap the order of phase partners. Normally phase partners are 1 and 2, 3 and 4, 5 and 6, 7 and 8. See below for an example of leading and lagging phases. Phase 1, 2, 5 and 6 are in barrier 1 and phase 3, 4, 7 and 8 are in barrier 2. The dark vertical line (at the end of phase 2/5) represents the barrier point.

Examples of Leading and Lagging Phases



Allow Lead/Lag Optimize?

If it is okay for this phase to be either leading or lagging, set this field to "Yes". If this phase must be lagging or must be leading, set this field to "Fixed".

Vehicle Extension

This is the also the Maximum Gap. When a vehicle crosses a detector it will extend the green time by the Vehicle Extension time.

Minimum Gap

This is the minimum gap time that the controller will use with volume-density operation. If volume-density operation is not used, set this value to the same as the Vehicle Extension.

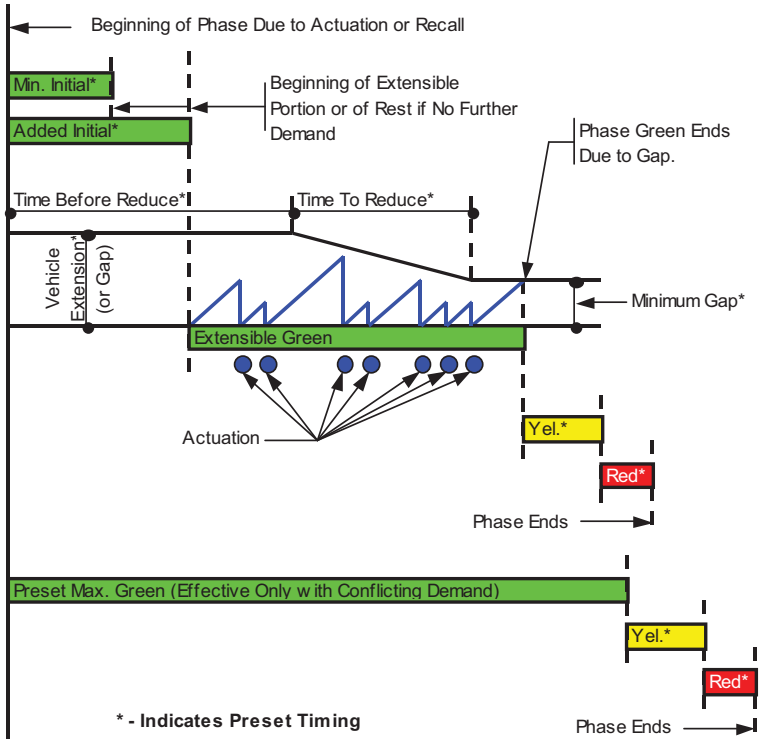
Time Before Reduce

When using volume-density operation, this is the amount of time before gap reduction begins.

HANDOUT

Time to Reduce

When using volume-density operation, this is the amount of time to reduce the gap from Vehicle Extension (or maximum gap) to Minimum Gap.



The graphic illustrates the minimum initial, vehicle extension, minimum gap, yellow, red and maximum preset green.

Recall Mode

Each phase can have a recall of None, Minimum, Maximum, or Ped. The coordinated phases can have C-Max or C-Min.

No Recall: The phase can be skipped.

Minimum Recall: The phase will always come on to its minimum, the phase can not be skipped.

Maximum Recall: The phase will always show its maximum and has no detection. The phase cannot skip or gap out, nor can it be extended.

Pedestrian Recall: The phase will always show a walk phase. The phase can't be skipped or gap out until the walk and don't walk intervals have passed.

C-Max: Phase shows for its maximum time starting at its scheduled start time.

C-Min: Phase shows for its minimum time starting at its scheduled start time. Coordinated movements must have detectors. No affect with By Phase yield points except with lead-lag phasing.

The C-Max, C-Min, Dual Entry and Inhibit Max are advanced controller features. Synchro 5 used C-Max, Dual Entry set to Yes and Inhibit Max set to Yes. It is common to use the defaults of Synchro 5 for many operations. These features will be discussed in more detail in the Level II class.

Dual Entry

Select Yes to have this phase appear when a phase is showing in another ring and no calls or recalls are present within this ring and barrier.

HANDOUT

Fixed Force Off?

Used for Actuated-Coordinated signals only. When Yes, a non coordinated phase can show more than its maximum time when it starts early.

Pedestrian Phase

Set this field to yes if there is a pedestrian phase for this movement.

Setting Pedestrian Phase to No will disable the ped phase and the input fields for walk, don't walk, and ped calls.

Walk Time

This is the amount of time for a pedestrian walk phase.

Flashing Don't Walk Time

This is the amount of time for a pedestrian Flashing Don't Walk phase.

Pedestrian Calls

This is the number of pedestrian push button calls for this phase. This value is only needed if this phase has a pedestrian push button.

HANDOUT

HANDOUT

HANDOUT

HANDOUT

2.7 Simulation Settings

From the **MAP** view, click on the desired intersection with the Right mouse button and select Simulation Options.

From anywhere in the program, press [**F8**] and select the desired intersection from the list. Then push the ***Simulatin Options*** *Settings* button or the [**F10**] key.

The **SIMULATION OPTIONS** setting displays a grid in which you can enter SimTraffic simulation specific information.

SIMULATION SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	350	1000	150	100	700	200	150	2000	250	100	600	2
Storage Length (ft)	250	—	200	250	—	200	150	—	200	150	—	2
Storage Lanes (#)	2	—	1	1	—	1	1	—	1	1	—	
Taper Length (ft)	25	—	25	25	—	25	25	—	25	25	—	
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Rig
Lane Width (ft)	12	12	12	12	12	12	12	12	12	12	12	
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	N
Median Width (ft)	—	24	—	—	24	—	—	12	—	—	12	
Link Offset (ft)	—	0	—	—	0	—	—	0	—	—	0	
Crosswalk Width (ft)	—	16	—	—	16	—	—	16	—	—	16	
TWLTL Median	—	☐	—	—	☐	—	—	☐	—	—	☐	
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.
Turning Speed (mph)	15	—	9	15	—	9	15	—	9	15	—	
Mandatory Distance (ft)	—	416	—	—	416	—	—	416	—	—	416	
Positioning Distance (ft)	—	1761	—	—	1761	—	—	1980	—	—	1980	
Mandatory Distance 2 (ft)	—	1174	—	—	1174	—	—	1320	—	—	1320	
Positioning Distance 2 (ft)	—	2348	—	—	2348	—	—	2640	—	—	2640	

Storage length for turning bay, in feet

Lanes and Sharing

Refer to the Lane settings, page 2-10.

Traffic Volume

Refer to the Volume settings, page 2-15.

Storage Length

The Storage Length is the length of a turning bay in feet (meters). If an intersection has a left turn storage bay of 150 feet (45 meters), enter "150" ("45") in this box. If the left or right turn lane goes all the way back to the previous intersection, enter "0".

Storage Length data is used for analyzing potential blocking problems, such as through traffic blocking left turn traffic, and left turn traffic blocking through traffic. If "0" is entered, no blocking analysis is performed.

Code Storage Lanes to reduce lane changes in SimTraffic. Mandatory lane changes can cause blocking of multiple lanes. Storage bays reduce the number of lane changes.

In the **Lanes and Sharing** row, code the number of lanes as they exist at the stop bar. Next, code any storage length on the left and right (independent of the movements that use the storage). Finally, enter the number of storage lanes on the left and right.

Refer to the examples in the text.

HANDOUT

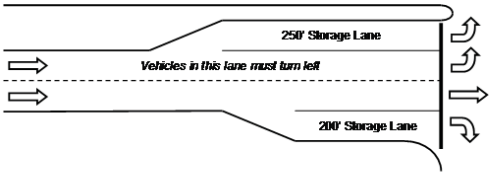
Storage Lanes

Code the number of lanes in the right or left storage bay. This value only appears when the storage length is greater than 0. By default the number of storage lanes is equal to the number of turning lanes.

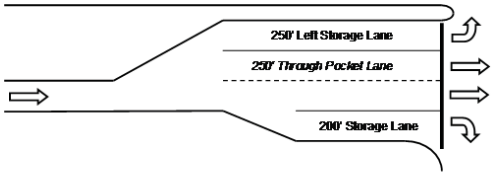
This field can be overridden so that some of the turning lanes are full travel lanes, or so that some of the through lanes can be storage lanes.

A red value indicates an override, while a blue value indicates that the number of storage lanes is calculated.

Examples of using Storage Length and Storage Lanes



SIMULATION SETTINGS	EBL	EBT	EBR
Lanes and Sharing (#RL)			
Traffic Volume (vph)	450	1125	200
Storage Length (ft)	250	—	200
Storage Lanes (#)	1	—	1



SIMULATION SETTINGS	EBL	EBT	EBR
Lanes and Sharing (#RL)			
Traffic Volume (vph)	450	1125	200
Storage Length (ft)	250	—	200
Storage Lanes (#)	2	—	1

Taper length

The Taper Length affects the visual **MAP** view drawing. In SimTraffic, the Taper Length impacts when vehicles can start entering the storage. The default is 25 ft (7.5 m).

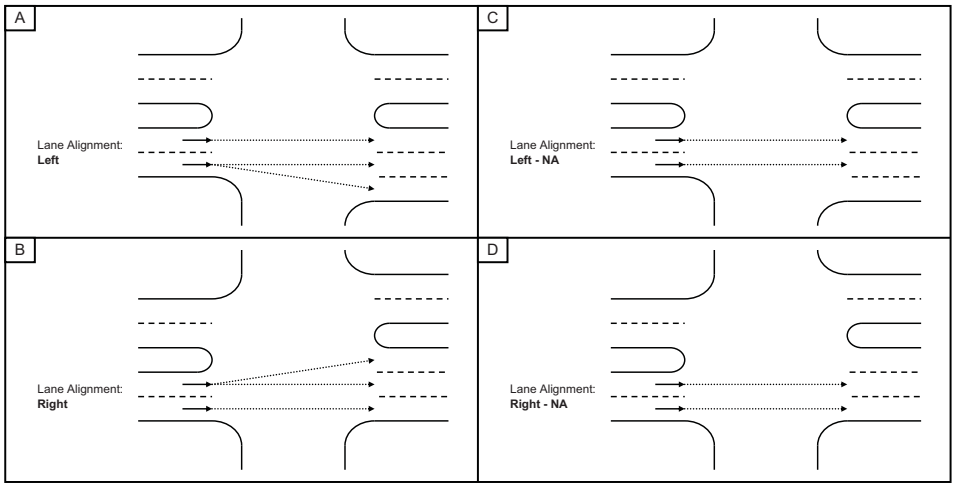
Lane Alignment

When adding a lane, lanes are added on the right or left. The setting will allow the user to specify how lanes align through an intersection. The choices are as follows:

A. Left
B. Right
C. L-NA (left, no add)
D. R-NA (right, no add)

The default is Right for right turns, Left for left turns and through, and Right-NA for U-turns.

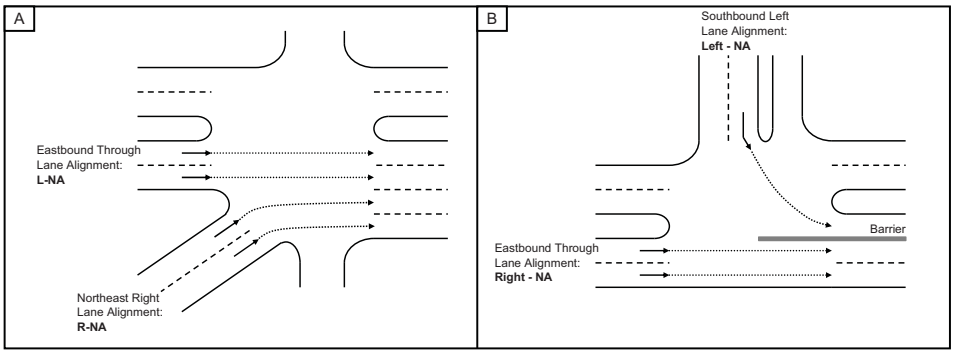
To see the intersection paths, go to Options>Map-Settings and check the box for Intersection Paths.



HANDOUT

Consider the examples in below. Part A shows an example where the EBT and NER are green at the same time. There are four upstream lanes (two EBT and two NER) flowing into four downstream lanes. In order to prevent a conflict, the EBT is forced to use the left lanes downstream by setting the Lane Alignment to L-NA. The NER is forced into the downstream right lanes by setting the Lane Alignment to R-NA.

Part B shows a T intersection with continuous flow in the eastbound direction. In this case, the EBT and SBL are allowed to operate without conflict. To do this, set the EBT Lane Alignment to R-NA and the SBL to L-NA.



Lane Width

Refer to page 2-12.

Enter Blocked Intersection

The **Enter Blocked Intersection** setting controls simulation modeling gridlock avoidance. The four options for modeling blocked intersections are "Yes", "No", "1" and "2". The default value is "No", for intersections and "Yes", for bends and ramp junctions. We suggest that you set Enter Blocked Intersection to "No", for high speed approaches and movements.

If vehicles are allowed to enter blocked intersections, gridlock within the roadway network could occur. This parameter should be used with caution.

A vehicle will slow for an intersection, if there are 4 other vehicles ahead of it, but behind the stop bar.

A side street of an unsignalized intersection can be set to 1 or 2. This will allow 1 or 2 vehicles to enter a blocked intersection from the side. This can help the capacity of driveways.

Median Width

The **Median Width** is used to set the width of the median. Left turn lanes are considered to be positioned in the median even if they are not defined as storage lanes.

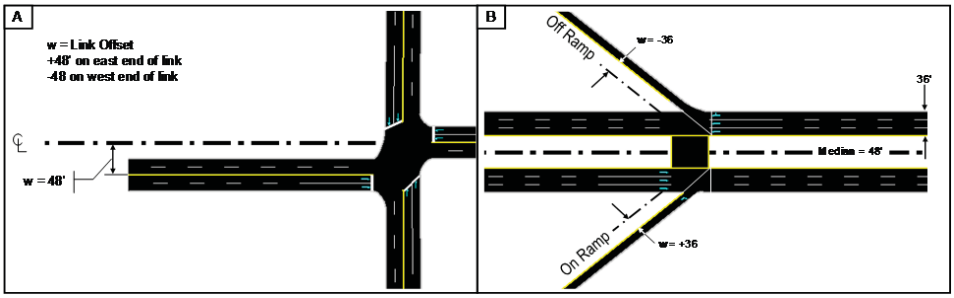
This setting can be overridden.

Link Offset

The **Link Offset** setting is used to offset the roadway alignment to the right or left of the centerline. This can be used to create a dog-leg intersection, if there are no internal stop bars (seethe figure below).

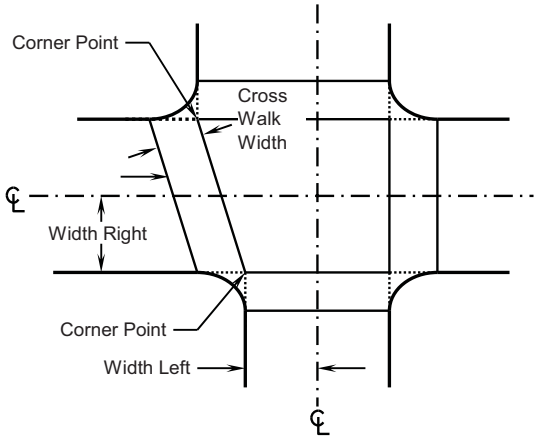
For an onramp or other acute intersection, use a positive link offset value for on-ramp, and a negative link offset value for an off-ramp. In the figure below, w is the width of the mainline lanes used as the link offset for each ramp.

HANDOUT



Crosswalk Width

The **Crosswalk Width** is used to control the width of the crosswalk and the location of the stop bar. The stop bar is located on the upstream end of the crosswalk.



TWLTL Median

The TWLTL Median is visual only. Vehicles will not use the TWLTL

The two-way left turn lane **(TWLTL) Median** setting draws a TWLTL in the median. The median will be colored with the pavement color and dashed yellow lines will be added. Storage taper lengths still apply. Setting the TWLTL "on" (check) will also set the TWLTL for the reverse link.

Notes about driveways

Avoid placing too many driveways along your link. Some driveways with short storage and taper lengths can be used. To reduce space of driveway intersections, set crosswalk width on the main street to 4ft. and draw the driveways at 90 degree angles.

Vehicles will not initiate or complete lane changes within an intersection. Too many driveways reduce opportunities for lane changes.

The TWLTL Median setting on one end of a link sets the TWLTL Median on the reverse end of the link.

Headway Factor

SimTraffic applies the **Headway Factor** to model Saturated Flow Rates for individual lane groups. Headway Factor is not used in any of the capacity calculations in Synchro.

The Headway Factor is based on the Ideal Saturation Flow, lane width factor, the grade factor, the parking factor, the bus stops factor, and the area factor. The headway factor is magnified by 30% because at cruise speeds, about 30% of the time per vehicle is taken by vehicle passage and 70% by the headways.

HANDOUT

$$HWF = \frac{1.3*1900}{fw*fg*fp*fbs*fa*Ideal} - 0.3$$ = Headway Factor

Where:

HWF = Headway Factor

fw = Adjustment Factor for Lane Width

fg = Adjustment Factor for Grade

fp = Adjustment Factor for Parking

fbs = Adjustment Factor for Bus Stops

fa = Adjustment Factor for Area Type

Ideal = Ideal Saturation Flow Rate

The Headway Factor is calculated but can be overridden.

Turning Speed

This is the **Turning Speed** for vehicles in miles/hour (km/h) while inside the intersection.

Synchro does not use this information. It is only used when modeling in SimTraffic.

The **NETWORK** settings have a network wide turning speed option. This setting affects the turn speed in CORSIM.

For large intersections or intersections with large turning radii, increase the Turning Speeds. This will give improved capacity in SimTraffic.

The Turning Speed should be adjusted if you are using SimTraffic to model a freeway section.

Turning speed is adjusted by driver speed factor.

Lane Change Distances

The **Lane Change Distances** are used for calibration of SimTraffic lane changing logic. Editing these values will not affect Synchro or CORSIM.

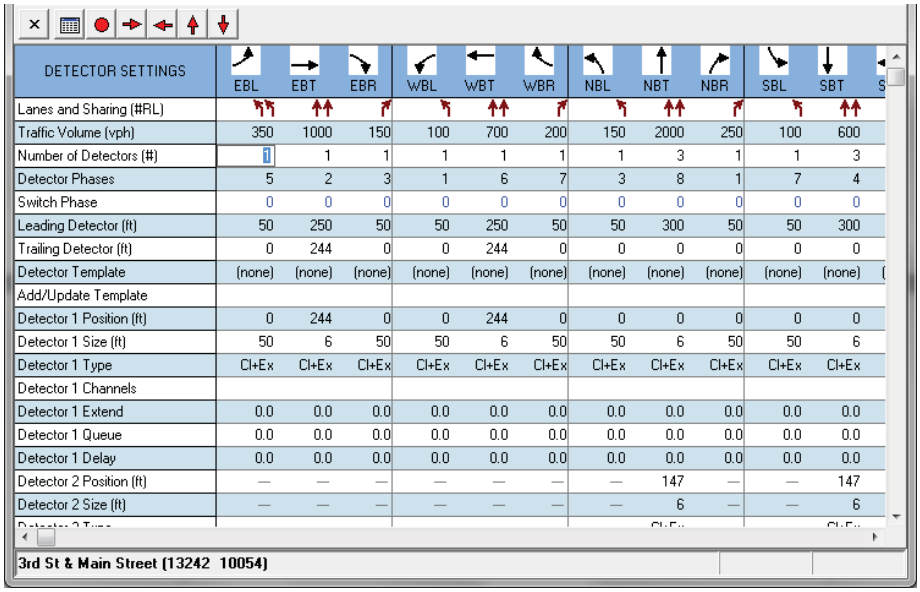
Refer to page 4-32 for additional details.

HANDOUT

2.8 Detector Settings

From the **MAP** view, click on the desired intersection with the Right mouse button and select Detector Options.

From anywhere in the program, press [**F8**] and select the desired intersection from the list. Then push the ***Detectors*** *Settings* button or the [**F11**] key. Clicking on a map detector also activates. The **DETECTOR** settings display a grid in which you can enter detector information.



DETECTOR SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT
Lanes and Sharing (#RL)											
Traffic Volume (vph)	350	1000	150	100	700	200	150	2000	250	100	600
Number of Detectors (#)	1	1	1	1	1	1	1	3	1	1	3
Detector Phases	5	2	3	1	6	7	3	8	1	7	4
Switch Phase	0	0	0	0	0	0	0	0	0	0	0
Leading Detector (ft)	50	250	50	50	250	50	50	300	50	50	300
Trailing Detector (ft)	0	244	0	0	244	0	0	0	0	0	0
Detector Template	(none)	(none)	(none)	(none)	(none)	(none)	(none)	(none)	(none)	(none)	(none)
Add/Update Template											
Detector 1 Position (ft)	0	244	0	0	244	0	0	0	0	0	0
Detector 1 Size (ft)	50	6	50	50	6	50	50	6	50	50	6
Detector 1 Type	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex
Detector 1 Channels											
Detector 1 Extend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Detector 1 Queue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Detector 1 Delay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Detector 2 Position (ft)	—	—	—	—	—	—	—	147	—	—	147
Detector 2 Size (ft)	—	—	—	—	—	—	—	6	—	—	6

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Number of Detectors

This is the number of longitudinal detector sets, not the number across the lanes. Detectors are numbered from the stop bar back, detector 1 is at the stop bar. You can enter up to 5 detectors.

Detector Phase

The Detector Phase is primary phase for a detector. This is the same as the Detector Phase setting in the **TIMING** settings.

There is only one detector phase and one switch phase per lane group.

Switch Phase

The **Switch Phase** is a secondary phase that extends the entered phase when it is green. This setting does not place a call and does not call the primary Detector Phase when the entered switch phase is green (per NTCIP specifications).

This setting can be used for the permitted phase of a permitted plus protected left turn. Do not use with a lagging left turn because the protected left will not get called while the permitted phase is green. The default for permitted plus protected is to have the Detector Phase equal to the Protected Phase and Switch Phase set to none.

HANDOUT

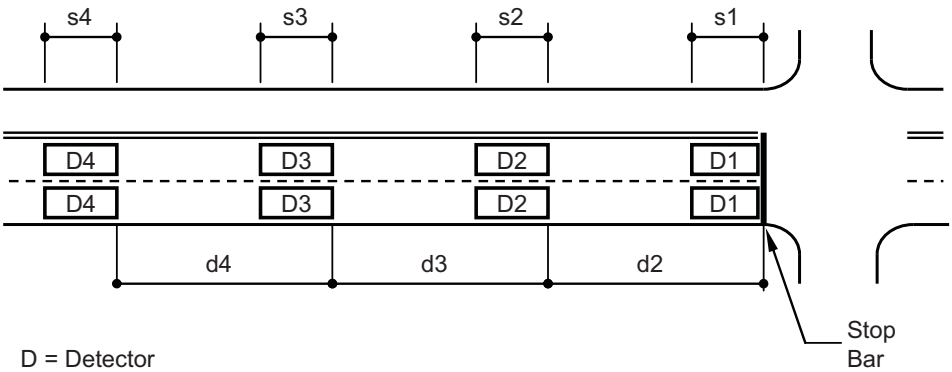
Leading Detector, Trailing Detector

Leading and **Trailing Detector** settings maintain backward compatibility with earlier versions of Synchro. The Detector Template method in Version 7 allows the user to specify the position, size, and call/extend value of each detector rather than accept the assumed geometry in the Leading/Trailing Detector method. The Detector Template automatically updates the Leading/ Trailing Detector fields.

Detector *n* Position

This is the distance from stop bar to the trailing edge (closet to stop bar) of detector *n*. This setting is for all lanes in the lane group.

Refer to the example below. In this example, detector 1 (D1) has a position of zero feet, detector 2 (D2) has a position of d2, detector 3 (D3) has a position of d2 plus d3, and detector 4 (D4) has a position of d2 plus d3 plus d4.



D = Detector
d = Distance
s = Size of Detector

Detector *n* Size

This is the size of the detector in the traveled direction. The default for detectors made from Leading Distance is 6 ft (1.8m). This setting is for all lanes in the lane group.

Detector *n* Type

The options are Calling, Extend, Cl+Ex; Calling places a call when the phase is yellow or red. Extend places a call when the phase is green. Options for delay, queue, and extend detectors are set by using a non-zero time for these options.

All detectors modeled in Synchro are presence detectors, not passage (or pulse) detectors.

Detector *n* Channel

Enter the detector number used by the controller. If there is a different detector channel for each lane, enter each value separated by columns. Traditionally the detector number is the same as the phase number, and one channel is used for all the detectors for a phase. Newer installations may have a separate detector input for each lane to allow volume counts. If the detector channels across three lanes (left to right) are 11,12, and 13; enter “11,12,13”.

The Detector Channel is not currently used by Synchro or SimTraffic, but can be imported and exported in UTDF data access. In the future there may be a conversion program to convert counts by detector number into counts by turning movement for use by Synchro.

Detector *n* Extend

Detector Extend, or "carry over" is specified in tenths of a second. This value extends the call for the specified value after the call drops.

HANDOUT

One application is to have 3 seconds extend time on advance detectors, and 0 extend time at the stop bar, in conjunction with a gap time of 0.5 seconds. This will allow the advance detectors to hold the phase green, while the stop bar detectors will not.

Detector 1 Queue

Enter the Queue time here to have the stop bar detector act as a queue detector, the old name is "Type 3 detector". A queue detector will extend the phase during the first *q* seconds, then be silent. Queue detection is useful for extending the phase during the queue clearance time, then later allowing the advance detectors to extend the phase.

If the stop bar detector extends the phase for 3 seconds, this will create 3 seconds of green after the last vehicle enters the intersection. This vehicle will be well beyond the intersection during the clearance interval. This will create extra delay for the opposing movements.

Detector 1 Delay

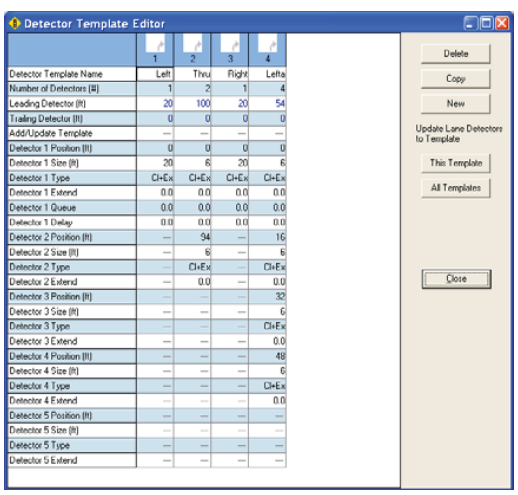
Enter the Delay time here to have the stop bar detector act as a Delay detector. A delay detector will not place a call on red or yellow, until the vehicle has been there for at least *d* seconds. A delay detector will extend normally on green. Delay detectors are useful for right turn lanes with right turn on red allowed; If a vehicle is able to turn on red within, for example, 10 seconds, it is not necessary to bring up this phase.

Detector Template

Detector Templates allow the user to define the number, position, type and size of each detector. Default templates named **Left, Thru,** and **Right** are used to setup detectors for new approaches. You can modify these templates, but you cannot remove them. It is recommended that you setup templates for all of the standard detector layouts your agency uses. Give them names such as "Thru 300" for through detectors located 300 feet in advance of the stop bar.

Add Template

Activate the Detector Template Editor by selecting **Options→Detector Templates**, or by double clicking on the left column of the DETECTOR settings. The Detector Template Editor allows the user to define additional templates in separate columns. Data fields are identical with the DETECTOR settings.



	1	2	3	4
Detector Template Name	Left	Thru	Right	Lefta
Number of Detectors (#)	1	2	1	4
Leading Detector (ft)	20	100	20	54
Trailing Detector (ft)	0	0	0	0
Add/Update Template	—	—	—	—
Detector 1 Position (ft)	0	0	0	0
Detector 1 Size (ft)	20	6	20	6
Detector 1 Type	Cl+Ex	Cl+Ex	Cl+Ex	Cl+Ex
Detector 1 Extend	0.0	0.0	0.0	0.0
Detector 1 Queue	0.0	0.0	0.0	0.0
Detector 1 Delay	0.0	0.0	0.0	0.0
Detector 2 Position (ft)	—	94	—	16
Detector 2 Size (ft)	—	6	—	6
Detector 2 Type	—	Cl+Ex	—	Cl+Ex
Detector 2 Extend	—	0.0	—	0.0
Detector 3 Position (ft)	—	—	—	32
Detector 3 Size (ft)	—	—	—	6
Detector 3 Type	—	—	—	Cl+Ex
Detector 3 Extend	—	—	—	0.0
Detector 4 Position (ft)	—	—	—	48
Detector 4 Size (ft)	—	—	—	6
Detector 4 Type	—	—	—	Cl+Ex
Detector 4 Extend	—	—	—	0.0
Detector 5 Position (ft)	—	—	—	—
Detector 5 Size (ft)	—	—	—	—
Detector 5 Type	—	—	—	—
Detector 5 Extend	—	—	—	—

The inputs on the Template are the same as those in the DETECTOR settings, except for the detector phase and detector channel.

HANDOUT

Select the [New] button to create an empty template and specify the template name.

Select the [Copy] button to duplicate the active column. The copied column will be inserted to the right. Data can be edited and template renamed.

The [Delete] button will remove the active column. The default Left, Thru and Right columns cannot be removed.

Use the Update Lane Detectors to Template [This Template] button to update all lane groups with that detector template name.

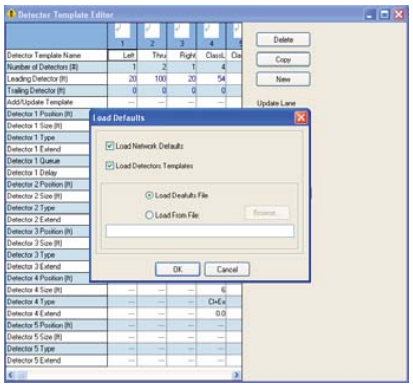
Use the Update Lane Detectors to Template [All Templates] button to update all lane groups with any detector template name.

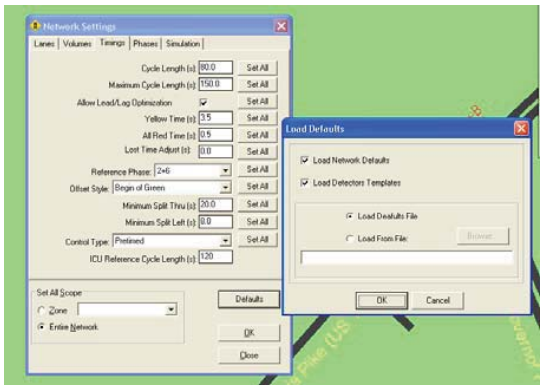
Detectors associated with a template are not automatically updated when the template is modified. Therefore, apply the Update Lane Detectors to Template button after modifying a template.

There is no cancel button. Use the undo command to rollback to the previous settings.

Default Detector Settings

The default detector settings are saved in the same defaults.syn file as all other default values. To load Detectors Templates you have to press **Defaults** in the Detector Template Editor and set the check box **Load Detector Templates**. After that you can use the saved default detector settings from defaults.syn or choose a Synchro file to load those templates. Also you can load Network Defaults by setting the "Load Network Defaults" checkbox.

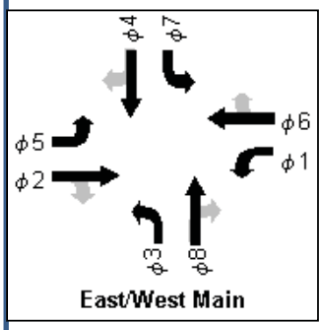


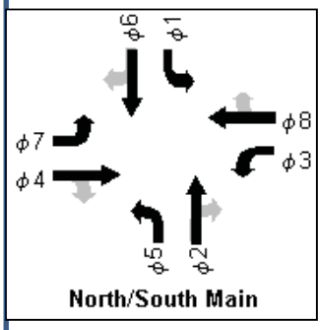


The same Load Defaults window will appear if you press "Defaults" button in the Network Settings window.

HANDOUT

If you do not plan to use your timing data for controller inputs (such as a planning study), the template phase you use is irrelevant. The primary purpose of setting up the phase templates is to match how they are in your controller. However, if your system is coordinated, use your main street direction phases as the coordinated phases.





Note: Be sure to check and establish appropriate pedestrian timings in the PHASING settings.

An existing conditions analysis is important to establish a base line, if there is an existing condition. This will assist the analyst in determining if the alternatives truly are better (and how much better).

2.9 Synchro Data Entry Quick Start

Entering data in Synchro can be intimidating for first time users. The purpose of this section is to give the basic steps that are required to quickly get your data entered. For a basic intersection, the steps would be as follows:

1. Draw your links then enter your lane and volume data for your intersection (see the sections on the **Map View**, **Lane** Settings and **Volume Settings**).
2. Choose the appropriate Phase Template (**Options→Phase-Templates**) to match your numbering convention. This step is necessary so Synchro can use the appropriate template when setting up Turn Types and phase numbers.

   This step is not required if you want to use the Synchro default template (North/South template) or if you are coding an unsignalized intersection or roundabout.
3. Choose your controller type. For signalized intersections, this can be set to a pretimed, semi-actuated uncoordinated, actuated-uncoordinated or actuated-coordinated (see page 2-21).
4. For unsignalized intersections, this can be set to an unsignalized (stop or yield controlled) or roundabout intersection.
5. Select the appropriate Turn Type for your left and right turns. This is the step where you will define how your turning movements are phased (protected, permissive, free, etc.). If you have defined the Phase Template in step 3, Synchro will automatically assign phase number for your turn treatments based on the diagram shown above. During this step, also identify your leading and lagging phases as necessary.

   If this is an unsignalized or roundabout intersection, you would select the appropriate sign control (stop, free or yield).

   Be sure to save your work frequently! Your data is stored in the SYN file and backed up in the ~YN file every time you save your work.
6. Input the appropriate phasing parameters (detailed in the section on Phasing Setting Inputs, page 2-25).
7. Enter the appropriate Cycle Length. If you are not performing an existing conditions intersection analysis, you can determine the cycle length by performing an intersection cycle length optimization (see page 3-5) or a network cycle length optimization (see page 3-7).
8. Adjust the phase splits with the Splits and Phasing diagram using your mouse. Move your mouse cursor to the right side of a yellow + all red band and it will change to the shape shown here . Hold down the left mouse button and move the mouse right or left to adjust the split.
9. For coordinated systems, enter your offset parameters (current offset, reference style and reference phase as shown on page 2-22).
10. If you plan to simulate, enter the necessary simulation settings, see page 2-29.
11. For detailed entry of detectors, see page 2-34.
12. Use the command **Options→Scenario-Manager** and update the Scenario information. This will appear on the Reports.

HANDOUT

3. LEVEL I – DAY 2

3.1 Analysis of Intersections

Percentile Green Times

There are five scenarios modeled. They are called the 90th, 70th, 50th, 30th, and 10th percentiles. Traffic volumes for each approach are adjusted up or down to model these percentile scenarios. By adjusting the traffic for different scenarios, the actuated signals can be modeled under a range of traffic conditions.

If traffic is observed for 100 cycles, the 90th percentile would be the 90th busiest, the 10th percentile would be the 10th busiest, and the 50th percentile would represent average traffic.

The expected number of vehicles, λ or 50th percentile, is the hourly flow rate divided by the number of cycles per hour.

$$\lambda = v * \frac{C}{3600}$$

$v = \text{Volume (vph)}$
$C = \text{Cycle Length (s)}$

The expected number of vehicles for a given percentile can be calculated using a Poisson distribution. The simplified formula to determine adjusted volumes is thus:

$$vP = v + \left[z * \sqrt{(v * C / 3600)} \right] * \frac{3600}{C}$$

For each percentile scenario and phase, a green time is given. The range of green times for each phase gives an indication of how often the phase will max-out, gap-out, or be skipped. Details on actuated green time calculations is shown in Section D.

Next to each green time is a code indicating how the phase terminates. Here is a list of codes.

sk	Phase is Skipped	pd	Phase held for pedestrian button or recall
mn	Phase shows for Minimum Time	mr	Phase has max-recall
gp	Phase gaps-out	dw	Main street phases dwells or green
hd	Phase held for other ring to cross barrier.	cd	Coordinated phase
mx	Phase maxes out.		

Synchro delay calculations will differ from the Webster/HCM based on differences in the methodology. Synchro uses a percentile delay method for calculating the delay for signalized intersections. In Synchro, the delay is based on five differing volume and cycle lengths (percentile volumes and green times). The delay answer is then a weighted average of five representative delays. The Webster/HCM method uses one cycle and one average volume to represent the analysis period.

Generally, the results will be similar if the actuated green times are used in the HCM method.

For coordinated and pre-timed signals, the actuated cycle will be the same as the Current Cycle Length.

Actuated Cycles

There are five scenarios modeled. They are called the 90th, 70th, 50th, 30th, and 10th percentiles. Traffic volumes for each approach are adjusted up or down to model these percentile scenarios. By adjusting the traffic for different scenarios, the actuated signals can be modeled under a range of traffic conditions.

If traffic is observed for 100 cycles, the 90th percentile would be the 90th busiest, the 10th percentile would be the 10th busiest, and the 50th percentile would represent average traffic.

For each of the percentile scenarios, this is the expected cycle length. This value is the sum of the actuated splits for each phase.

If you use the Optimize→ Intersection-Cycle-Length command, the intersection will be set to the Natural Cycle Length.

HANDOUT

HANDOUT

Actuated Cycle Length

The Actuated Cycle Length (CL) is the average cycle length for five percentile cycle lengths.

Natural Cycle Length

Natural Cycle Length is the shortest cycle length that will give acceptable capacity. In general, intersections have an optimum cycle length that provides the best level of service. The Natural Cycle Length is the cycle length this intersection would operate at if it were to operate independently of all other intersections.

Actuated Effective Green

This value represents the average green time observed while the signal is operating in actuated mode (average of five Percentile green times). This value may be less than **Maximum Green** time if the phase is skipped or gapped out. The actuated green time may be higher than the Maximum Green time for Coordinated and Dwelled phases. This value is used for the HCM Signal Report calculations.

Capacity, c is based on the saturation flow multiplied by the green to cycle (g/C) ratio. Therefore, if v/c > 1.0, to reduce this you can reduce volume, v; reallocate green time, g/C; or increase the saturation flow, s (increase lanes).

Actuated Green to Cycle Ratio

This if the average actuated green time divided by the actuated cycle length. This value indicates what portion of the green per cycle is given to this subject movement.

Volume to Capacity Ratio

The movements Volume-to-Capacity Ratio (v/c Ratio) is the v/c ratio using actuated green times and cycle lengths. If this value exceeds 1.0, this indicates that the volume is exceeding the available capacity.

Synchro strictly follows the methods of the 2000 HCM for unsignalized intersections. This method does not provide for a queue delay. Therefore, a queue delay will not be reported for any unsignalized intersection. If this is important, then consider simulating the network with SimTraffic.

Control Delays

This is the Percentile Delay for each lane group. This is based on five percentile volumes and green times.

Queue Delay

Queue Delay is an analysis of the affects of queues and blocking on short links. This delay includes the analysis of Spillback and Starvation. Additional details on Queue Delay and queue interactions can be found in the Synchro Help topic, Queue Interactions.

Total Delay

Total Delay is the lane group Control Delay plus the Queue Delay.

Level of Service

The Level of Service for the lane group is calculated by taking the Delay and converting it to a letter, between A and F, based on the length of the delay.

LOS	Signalized Total Delay Per Vehicle (s)	Unsignalized Control Delay Per Vehicle (s)
A	≤ 10	≤ 10
B	>10 and ≤ 20	>10 and ≤ 15
C	>20 and ≤ 35	>15 and ≤ 25
D	>35 and ≤ 55	>25 and ≤ 35
E	>55 and ≤ 80	>35 and ≤ 50
F	>80	>50

Keep in mind that the unsignalized delay does not include queue delay.

HANDOUT

Approach Delay

This is the delay for the direction approach based on the weighted average of the lane groups for this direction.

Approach Level of Service

This is the approach LOS based on the approach control delay using the same table above.

Queue Lengths

The **Queue Length** rows show the 50th Percentile and 95th Percentile **Maximum Queue** lengths. The 50th percentile maximum queue is the **maximum back of queue** on a typical cycle and the 95th percentile queue is the maximum back of queue with 95th percentile traffic volumes.

If traffic were observed for 100 cycles, the 95th percentile queue would be the queue experienced with the 95th busiest cycle. The 50th percentile queue would represent the queue under average traffic.

The ~ and # footnote indicate that the volume modeled exceeds capacity. The ~ footnote indicates that the approach is above capacity and the queue length could be much longer. The queue length is theoretically infinite and blocking problems may occur. The value shown for the 50th percentile queue is sufficient to hold one cycle of traffic. This will prevent capacity problems from being compounded by insufficient storage space.

The # footnote indicates that the volume for the 95th percentile cycle exceeds capacity. This traffic was simulated for two complete cycles of 95th percentile traffic to account for the affects of spillover between cycles. If the reported v/c <1 for this movement, the methods used represent a valid method for estimating the 95th percentile queue. In practice, 95th percentile queue shown will rarely be exceeded and the queues shown with the # footnote are acceptable for the design of storage bays.

The m footnote indicates that volume for the 95th percentile queue is metered by an upstream signal.

Important: Queue lengths are determined in different methods between Synchro and SimTraffic. Therefore, it is likely that they will not match.

Synchro is a macroscopic software package and uses analytical methods for calculating the queue. In other words, equations are used to determine the queue length. When volume exceeds capacity, the limits of the equations are exceeded.

SimTraffic is a microscopic simulation program that actually "observes" the queues. The model simulates the vehicle and reports whenever a vehicle is traveling less than 10 ft/s and is behind a queue of vehicles. This distance then gets reported. At the end of the period, SimTraffic determines the maximum, the average of 2 minute maximums, and the 95th percentile queue.

Critical Gap

The critical gap, tC, is defined as the minimum length of time interval in the major street traffic stream that allows intersection entry for one minor street vehicle. The value in Synchro is the value that is defined by equation 17-1 from the HCM.

This value can be over-ridden.

This value is only used for HCM unsignalized calculations and will have no impact on the SimTraffic simulation.

For two-stage gaps, the Critical Gap is the combined single stage tC. When two-stage, each stage is 1 second less.

Follow-up Time

The follow-up time is the time span between the departure of one vehicle from the minor street and the departure of the next vehicle using the same major street gap, under a condition of continuous queuing on the minor street. The value in Synchro is the value defined by equation 17-2 after adjusting for heavy vehicles.

This value can be over-ridden.

This value is only used for HCM unsignalized calculations and will have no impact on the SimTraffic simulation.

The delay shown in the TIMING Settings is the Percentile delay. This is the same delay that will be shown in the 'INT:' reports.

Maximum v/c Ratio

This field shows the maximum Volume-to-Capacity ratio of all individual v/c ratios.

HANDOUT

Intersection Delay

The Intersection Delay field shows the average delay for the intersection and it is calculated by taking a volume weighted average of all the delays. This delay will be the Synchro Control delay which is based on the Percentile method.

Intersection Level of Service

This LOS will be on the Synchro Control delay. The Level of Service for the intersection is calculated by taking the Intersection Delay and converting it to a letter using the Table previously described.

The ICU is shown for un-signalized intersections since it represents the potential capacity for the intersection if it were to be signalized.

Intersection Capacity Utilization

This is the Intersection Capacity Utilization (ICU) for the intersection based on the ICU 2003 method. Full details of the ICU can be found in the topic, Intersection Capacity (ICU) Report in the Synchro Help file. There is also an ICU document and spreadsheet in your Program Files/Trafficware directory.

ICU Level of Service

Do not confuse the ICU LOS and the delay LOS. They are based on different criteria so they are not comparable.

The ICU Level of Service (LOS) gives insight into how an intersection is functioning and how much extra capacity is available to handle traffic fluctuations and incidents. ICU is not a value that can be measured with a stopwatch, but it does give a good reading on the conditions that can be expected at the intersection.

A letter A to H based on the table and the Intersection Capacity Utilization. Note that the ICU 2003 includes additional levels past F to further differentiate congested operation.

LOS	ICU Level of Service
A	≤55.0%*
B	>55% to 64.0%
C	>64% to 73.0%
D	>73% to 82.0%
E	>82% to 91.0%
F	>91% to 100.0%
G	>100% to 109.0%
H	>109%

Warning Indicators

The lower right cells of the Synchro window indicate potential intersection coding errors or timing problems when Red. Green indicates no errors.

Conflict indicates a phase or coincident phase(s) serve conflicting movements. Look at the Protected Phasing row for red phase numbers. No conflict checking is performed on permitted phases.

v/c > 1 indicates that Volume exceeds capacity for one or more movements. It may also indicate volume was coded without lanes or green time. Look at the v/c row for values greater than 1 or for "No Cap" errors. For congested intersections, a v/c >1 error may be unavoidable.

Min Err indicates that one or more splits violate minimum timing requirements. Look at the Total Split row for values in red. Also compare the Maximum Split in the **PHASING settings** to the Minimum split. A Min Err may also occur if timings are too short for pedestrian timings.

HANDOUT

3.2 Intersection Optimization

Optimize-Intersection Splits

The **Optimize→Intersection-Splits** command will automatically set the splits for all the phases. Time is divided based on each lane group's traffic volume divided by its adjusted saturated flow rate. The Split Optimizer will respect **Minimum Split** settings for each phase whenever possible. See page 4-21 for additional information.

Synchro attempts to provide enough time during the split optimization to clear 90th percentile traffic flows. This ensures enough time is available for volume fluctuations.

Optimize-Intersection Cycle Length

The Natural Cycle length is the lowest acceptable cycle length for an intersection operating independently. The natural cycle length appears on the **TIMING** Settings.

The **Optimize→Intersection-Cycle-Length** command will set the intersection to the Natural Cycle Length.

If you optimize the cycle length, the splits will be automatically optimized to fit into the new cycle length.

The Natural Cycle Length will be one of three possibilities.

1. Shortest Cycle Length that clears the critical percentile traffic.
2. Cycle Length with the lowest Performance Index, provided lowest PI cycle is less than cycle found in (1). This option is used to give reasonable cycles for intersections over capacity.
3. If no cycle is able to clear the critical percentile traffic, but a shorter cycle is able to give satisfactory v/c ratios, the shorter cycle length will be used. This is a special case to handle near capacity intersections with permitted left turns.

Note: Each project does not require every optimization menu command. For instance, whenever you change the cycle length (manually, intersection-optimize or network-optimize) the splits are automatically optimized. Therefore, it would be redundant to optimize the splits after optimizing the cycle length.
See page 4-22 for additional examples of when to use these menu commands.

Optimize-Intersection Offsets

To change a single intersection's timing plan so that it works best with its neighbors, click on an intersection to select it, then choose the **Optimize→Intersection-Offsets** command. This command tests all possible offsets and lead-lag combinations. This command chooses the timing plan for this intersection that minimizes delays on links between this intersection and its immediate neighbors.

For each offset and lead-lag combination Synchro will reevaluate the departure patterns at this and surrounding intersections and recalculate delays. Synchro will also recalculate skipping and gap-out behavior at actuated-coordinated intersections.

When optimizing offsets, Synchro will look at offsets every 16 seconds around the cycle. Synchro will take those with the lowest delay score and look at offsets nearby every 4 seconds. Synchro will then take those with the lowest delays and look at offsets nearby every 1-second.

This command only changes the selected intersection. It does not make any changes to surrounding intersections. There may be better timing plans available by changing the timings of surrounding intersections, but Optimize-Intersection Offsets and Phasing will not find them. To find the best timing plans overall, use the **Optimize→Network-Offsets** command.

HANDOUT

3.3 Network and multi-system optimization

Synchro contains a number of optimization functions. It is important to understand what each function does and use the optimizations in the correct order.

Step 1: Single Intersection Timing Plans

The first step is to make timing plans for each individual intersection. This is the process of determining the phase sequences, left turn treatments and any other special phasing patterns. If this is an existing condition, the single intersection timing plan may already be established.

Step 2 is used to break networks into Zones. If you already have your zones determined, you can skip Step 2.

Step 2: Partition Network (Optional)

The next step is to divide the network into subsystems. This step is optional. It is up to engineering judgment to decide whether to partition a network. This will change the zone names.

Step 3: Optimize Network Cycle Length

The next step is to determine a system cycle length. It is possible to assign a different cycle length to each zone and create multiple zones (see below).

Step 4: Optimize Offsets, Lead-lag Phasing

After determining a system cycle length (or several cycle lengths), the last step is to optimize offsets. Use the Synchro command **Optimize→Network-Offsets**.

Tips to Improve Optimizations

Be sure to set the *Maximum Cycle Length* using the **Option→Network-**Settings command. Congested intersections may be set to the Maximum Cycle Length in many situations.

If there are permitted left turn movements with a v/c of greater than 1, consider making a protected left turn phase or prohibiting left turns at this intersection.

If you find that there are blocking problems between closely spaced intersections, consider using alternative phase orders, such as lagging lefts, lead-lag phasing, or split phasing. If you set the **Allow Lead/Lag Optimize?** field in the **PHASING settings** to "Yes" then Synchro will try both leading and lagging for that phase.

When optimizing Offsets, optimizing the Lead-Lag Phasing slows down the optimization process. If you want a faster optimization, turn off **Allow Lead/Lag Optimize?**.

The Cycle Length Optimization can take quite a while. Consider limiting the number of cycles evaluated.

CF = Max(CF1, CF2) + Ap + Av + Ac

Where,
- CF = Coordinatability Factor
- CF1 = Initial Coordinatability Factor from Travel Time
- CF2 = Initial Coordinatability Factor from Volume per Distance
- Ap = Platoon Adjustment
- Av = Volume Adjustment
- Ac = Cycle Length Adjustment

Coordinatability Factor

The Coordinatability Factor (CF) is a measure of the desirability of coordinating the intersections. Several criteria are used in an attempt to determine whether coordination is warranted. These criteria are used to determine a CF on a scale from 0 to 100 or more. Any score above 80 indicates that the intersections must be coordinated to avoid blocking problems; any score below 20 indicates the intersections are too far apart, or coordination is otherwise not desirable.

The CF is used with the Partition Network optimization. Intersections with CF values above the threshold CF are placed in the same zone or signal system.

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The CF is also used with cycle length optimization when uncoordinated intersections are allowed. Intersections with CF values below the threshold CF are allowed to be independent and uncoordinated.

To see a detailed listing of the factors of the CF select the File→Create Report command and include a report for Coordinatabilities, or double-click on any link while the CFs are displayed.

Summary of Coordinatability Factor

To see CFs select the ***Show Natural Coordinatability Factors*** button or the ***Show Current Coordinatability Factors*** button. The CF for each link will appear on the map.

Current versus Natural Coordinatability Factor

The Current Coordinatability Factor uses the current cycle length and timings to calculate the CF. The Natural Coordinatability Factor uses the intersection's natural cycle lengths. The Natural CF is used to initially determine which intersections should be coordinated. The Current CF is used to analyze the current timing plan and justify whether or not to coordinate additional intersections.

To answer the question, 'why were these two intersections coordinated together?', look at their natural CF. To answer the question, 'why are these two intersections not coordinated together?', look at their current CF.

Partition Network (Optional Step)

Choose **Optimize→Partition-Network** to divide a network into multiple systems. Each intersection is assigned a zone. Existing Zone assignments will be changed. **This command does not actually change timings**, but it sets up the network to have multiple cycle lengths when Optimizing Network Cycle Lengths.

The partition network optimization calculates Coordinatability Factors (CFs) for each pair of adjacent intersections. Any intersections with a CF above the threshold value are put into the same zone.

The CF value will range between 0 and 100. When choosing a Partitioning strategy the number in parenthesis is the threshold CF. If *One System* is selected all connected intersections will be placed in the same zone.

Example: Assume you have node 1 and 2 with a Coordinatability Factors equal to 60 between them. If you choose the Partition Network strategy "Divide Sometimes (50)", the two nodes will be placed in the same zone since 60 is greater than 50. If you choose the Partition Network strategy "Divide Often (70)", the two nodes will be placed in different zones.

Optimize-Network Cycle Lengths

Choose the **Optimize→Network-Cycle-Lengths** command to optimize cycle lengths for the network.

The best cycle length is found by calculating a performance index.

The PI is calculated as follows.

PI = [D * 1 + St * 10] / 3600

D = Delay in Seconds
St = Stops

Optimize Network Cycle Lengths Options

Minimum, Maximum, and Increment Cycle Length: Enter the minimum and maximum cycle lengths to evaluate. The optimizer will evaluate every cycle length between the minimum and maximum at increment intervals. If the values are set to 60, 100, and 10; the optimizer will evaluate cycle lengths of 60, 70, 80, 90, and 100 seconds.

Allow Uncoordinated: This option will recommend some intersections to be uncoordinated. The number in parentheses is the threshold Coordinatablity Factor (CF). Intersections will be made independent when the following apply:

1. CF with all neighbors is less than threshold CF.
2. Space required for one cycle of traffic less than 80% of storage space.
3. If the sum of Minimum Splits exceeds the Evaluation Cycle, the intersection will be set to uncoordinated.

Allow Half Cycle Length: This option will place some intersections at half cycle length. This option can give snappier operation and less delay at less congested intersections. Half Cycle

If Allow Half Cycles is selected, only even numbered cycle lengths will be evaluated. If min, max, and incr are set to 80, 120, and 5, and half cycles are allowed, the optimizer will evaluate 80, 86, 90, 96, 100, 106, 110, 116, and 120.

HANDOUT

Intersections will be given a cycle length of 1/2 the evaluated cycle. Intersections will be half cycled when they meet the following criteria:

1. Natural Cycle ≤ Evaluation Cycle / 2
2. Space required for one cycle of traffic less than 120% of link storage space.

Preserve Files: With this option a file is saved for each cycle length. These files can be loaded afterwards for evaluation or used for a multi-file comparison report. The files are given the name "filename-050.sy5" where filename is the name of the file and 50 is the cycle length.

Offset Optimization: Choose Quick to evaluate many cycle lengths quickly. Choose Medium or Extensive to analyze several cycle lengths in detail.

Automatic: The automatic option will automatically select the best cycle length based on the cycle with the lowest Performance Index (PI). It is possible to have each zone assigned a different cycle length.

Manual: The manual option will create a table of cycle lengths with MOEs listed. The user can choose the "best" cycle length. Each zone can be assigned its own cycle length or all zones can be assigned a single cycle length.

Manually Selecting a Cycle

After performing a manual cycle length optimization, the **SELECT CYCLE LENGTHS** window will appear. Each cycle has MOEs listed for Percentile Delay, Stops, Fuel Consumption, Unserved vehicles, Dilemma vehicles and speed.

Master Intersection

In Synchro there is one or zero master intersections for each cycle length. Half cycled intersections share the master. When changing offsets it is possible to combine two masters into the same cycle length and only one intersection will remain master.

A common misconception is that there is one master per zone. This is not true, there is one master per cycle length. Two zones with one cycle length can have only one master, even if they are not physically connected.

Optimize-Network Offsets

The final step to Network optimization is to optimize offsets. This step should be performed after the cycle length has been determined.

Choose the Optimize→Network-Offsets command.

The objective of the network offset optimization is to minimize the delay.

Often, users will ask if a direction can be 'favored'. Since delays are already volume weighed, Synchro directly favors the directions with the higher volume.

Scope

Choose **Zone** and enter a zone to perform optimizations on a group of intersections. To select multiple zones, separate the zones with a comma.

Choose **Entire Network** to optimize the entire network.

Optimizations

Optimize Splits will perform a Split Optimization for all intersections in the current scope. Cycle lengths are not affected. Perform this step if volumes or geometry has changed since the cycle length has changed.

Offset Optimization Speed controls how many optimization passes are performed and the step size of each pass.

HANDOUT

The **Step Size** controls how many offsets are looked at with incremental offset optimization. Using a value of 1 will check offsets in 1-second intervals. Using a value of 2 will check offsets in 2-second intervals and take less time. It is recommended that offsets be optimized with a step size of 4 first and followed with a step size of 1.

[OK] starts the optimization process. All of the checked optimizations will be performed in order.

Do not select **Optimize Splits** after performing a cycle length optimization. These values are already optimized and any incremental optimization will be lost.

Allow Lead/Lag Optimize? is enabled for some passes. This feature will try reversing phase orders to improve coordination. This optimization is only performed for phases with **Allow Lead/Lag Optimize?** set to **Yes**.

Weighing

Optimize Splits will perform a Split Optimization for all intersections in the current scope. Cycle lengths are not affected. Perform this step if volumes or geometry has changed since the cycle length has changed.

HANDOUT

HANDOUT

HANDOUT

HANDOUT

3.5 Program Reports

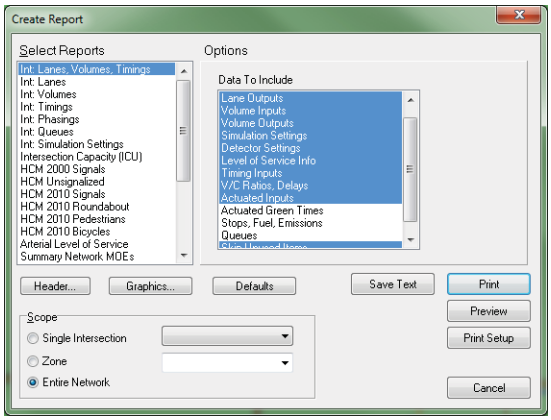
Printing Windows

To print the current window type [Ctrl] + [P]. This will print the currently active **Map View**, or the **TIME-SPACE DIAGRAM** to the current printer. When you select the **File→Print-Window** command from the **VOLUME**, **LANE**, **TIMING**, **PHASING**, **SIMULATION** or **DETECTOR** screen, a report is created containing information from that view.

If you choose the 'Int:' reports with delay, this is the same delay as found in the **TIMING** Settings.

Select Reports Window

When choosing the **File→Create-Report** command, the **Select Report(s)** window appears. From this window you can select the reports to include and options for each report.



Zoom in the Report Preview

A Zoom control has been added to the Report Preview window to preview the report using a bigger or smaller scale.

Use the **Header** button to change the header and footer information on your report.

Choose the **Graphics** button to change fonts, row shade colors, horizontal lines, fonts and picture attributes.

Save-Text will print the selected report to a text file. This can be opened with any text editor. It can also be opened with a spreadsheet (tab delimitated) and formatted for your special reports.

Intersection Reports

There are 7 **Intersection Reports**. These begin with 'Int:' for the name in the Select Reports box. These reports provide information about individual intersections. Each of these reports can be customized with the Options panel of the right sides. The **Lanes, Volumes, Timings, Phasings** and **Simulation** Settings reports contain the same information found in the data entry screens. The **Queues report** contains information about queues and blocking.

Intersection Queue Report

The Intersection Queue report contains information about Maximum Queue Lengths, Blocking Information and Queue Delays.

The Queue report shows the 50th Percentile and 95th Percentile **Maximum Queue** lengths. See the User Guide for further details.

The ~ footnote indicates that the approach is above capacity for the 50th percentile traffic and the queue length could be much longer. The queue length is theoretically infinite and blocking problems may occur.

Use File>Print-Window to print the current Map View to your printer.

The # footnote indicates that the volume for the 95th percentile cycle exceeds capacity. This traffic was simulated for two complete cycles of 95th percentile traffic to account for the affects of spillover between cycles.

Queue Delay is an analysis of the affects of queues and blocking on short links.

HANDOUT

Base Capacity is the capacity of the lane group if unimpeded. Capacity is the lane group saturation flow multiplied by the lane group green to cycle ratio.

The **Starvation Capacity Reduction** is the reduction to the base capacity due to starvation.

Spillback Capacity Reduction is a reduction to the base capacity caused by a short downstream link becoming filled up.

Intersection Capacity (ICU) Report

The Intersection Capacity Utilization provides a straightforward method to calculate an intersection's level of service. The method simply takes a sum of the critical movements volume to saturation flow rates.

Additional Details can be found in the *Intersection Capacity Utilization 2003* book. A copy of this book can be obtained from Trafficware.

ICU is an ideal solution for traffic planning purposes. Its intended applications are for traffic impact studies, future roadway design, and congestion management programs. The ICU is not intended for operations or signal timing design. The primary output from ICU is analogous to the intersection volume to capacity ratio. Other methods such as Synchro and the HCM should be used for operations and signal timing design.

The ICU does not provide a complete picture of intersection performance, but it does provide a clear view of the intersection's volume related to its capacity. Compared to delay based calculations, the ICU is relatively easy to calculate and does not include the opportunities for guessing and manipulation found in the HCM.

The ICU is timing plan independent. It makes no analysis about the currently implemented signal timing plan. The ICU can be applied to an unsignalized intersections and give information about the ultimate capacity of an unsignalized intersection if it were signalized.

HCM 2000 Signal Report

This report provides a full implementation of the HCM 2000 Signalized Operations method. See page 4-3 for details on how Synchro delays compare to HCM delays.

The HCM Signal Report now includes a RTOR reduction calculation. The Lane Group Flow is now equal to the Adjusted Lane Group flow minus the RTOR reduction.

Synchro delay calculations (Int: Reports and TIMING Settings) will differ from the HCM Signal Report based on differences in the methodology. Synchro uses a percentile delay method for calculating the delay for signalized intersections. Details on this methodology can be found in the Synchro Help topic "The Percentile Delay Method". The HCM Signal Report strictly follows the methods of the year 2000 Highway Capacity Manual, Chapter 16.

Refer to the note on page 3-1 for additional information.

HCM Unsignal Report (2000)

The HCM Unsignalized Report is based on the HCM 2000 Chapter 17.

From page 10-7 of the HCM:

"The portion of the urban street being analyzed should be at least 1 mi long in a downtown area and 2 mi long elsewhere for the LOS speed criteria to be meaningful. Study lengths shorter than 1 mi. should be analyzed as individual intersections and the LOS assessed according to individual intersection criteria."

HCM 2010 Signal Report

This report is for the 2010 HCM Signal methods as described in Chapters 18 and 31 and as implemented in the available computational engine.

HCM 2010 Pedestrian Report

This report is based on the 2010 HCM Pedestrian methods for signalized intersections.

HCM 2010 Bicycle Report

This report is based on the 2010 HCM Bicycle methods for signalized intersections.

HCM 2010 Roundabout Report

This report is based on the 2010 HCM Roundabout methods.

HANDOUT

Arterial Level of Service Report

The Arterial Level of Service report contains information about the speed and travel time for an arterial. This report mirrors the reports used in the Arterials section of the HCM (year 2000), Chapter 15 with concepts defined in Chapter 10. The Arterial report can also be compared with field travel time studies.

A report is created for each direction of the arterial.

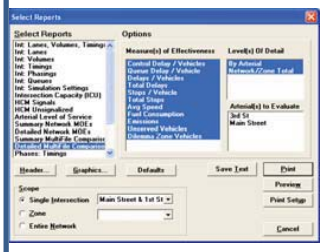
Network Measures of Effectiveness Report

The MOE reports display quantitative information about the performance of intersections and the network.

The MOEs can include delays, stops, fuel consumption, queuing penalty, dilemma vehicles and emissions.

The network reports can display information about each approach, each intersection, for an arterial, and for the entire zone or network selected.

Multi-File Comparison Report

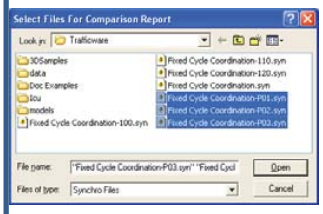


The Multi-file Comparison Report is used to compare multiple alternatives (files) side-by-side.

The report could be used to compare a before and after condition, or the report can be used to compare MOEs for two or more different timing plans.

The first page of the comparison report lists each alternative with its scenario information and basic statistics.

Succeeding pages list the MOEs with one column for each alternative. The MOE information follows all of the rules for the Network report.



To create a multi-file comparison report, choose 'Detailed Multifile Comparison' in the Select Reports window and select the MOE's that you want to include. Then select [Print] or [Preview] and a window will appear asking which files to compare. If you do not see your files, type *.syn (*.syn for Synchro 6 files) in the File Name box. All of the files that you want to compare must be in the same directory. When you see the files you want to compare, click on the first one, then hold the [Ctrl] key and select the second, third, fourth and so on and select [Open].

Phases: Timings Report

Timing Report, Sorted by Phase Number option provides information about the signal timing parameters determined by Synchro.

Most of these values are the same values shown in the **TIMING** settings or **PHASING** settings.

The Timing report (Phases: Timings) also includes a start time, an end time, a yield/force off and yield/force off 170. These times are phase references to the beginning of the system clock. The 170 yield (to the coordinated phase) is referenced to the beginning of the flashing don't walk.

Actuated Start and Green Times Summary

The Actuated Phase Start and Green summary report shows the green time for each phase along with the phases' start time. This information is provided for each of the five percentile scenarios. This report is helpful for looking at actuated signals in coordination, to see if phases may be starting early.

HANDOUT

Actuated: Details

The Actuated Phase Start and Green summary report shows the green time for each phase. This information is provided for each of the five percentile scenarios. This report is helpful for looking at actuated signals to see the range of green times.

Actuated Phase Details

The Actuated Phase Details report shows the green and yellow time for each phase alongside the time to clear the queue and the time to gap out. This information is provided for each of the five percentile scenarios. This report is helpful to observe in detail the operation of actuated phases.

Permitted Left Turn Factors Report

The Permitted Left Turn Factors report provides information about the lanes and saturation flow rates. It is roughly equivalent to the HCM's Supplemental Worksheet for Permitted Left Turns.

For details on all of these values, refer to the 1997 HCM, pages 9-17 to 9-22. The value Flt is the permitted left turn factor that is seen in the **LANE window**.

FLT is calculated based on maximum green times rather than actuated green times. This may cause the Synchro FLT to vary slightly from the HCM calculations.

Coordinatability Analysis Report

The Coordinatability Analysis report gives information about Coordinatability factors and elements used to calculate them.

Each element that affects the Coordinatability Factor (CF) is shown, along with the affect it has on the CF. A CF ranges from 0 to 100 or more. Any value above 50 means that coordination is recommended. The higher the CF, the more likely that this link will benefit from coordination.

The factors used to determine Coordinatability are as follows:

Travel Time
Traffic to Storage Space
Proportion of Traffic in Platoon
Main Street Volume
Increase in Cycle Lengths needed for coordination

HANDOUT

3.6 Synchro Integration with SimTraffic

SimTraffic is a companion product to Synchro for performing microscopic simulation and animation. SimTraffic uses a Synchro *.syn file for input.

SimTraffic includes the vehicle and driver performance characteristics developed by the Federal Highway Administration for use in traffic modeling. The underlying formulas represent over 20 years of research into traffic modeling.

SimTraffic Operation

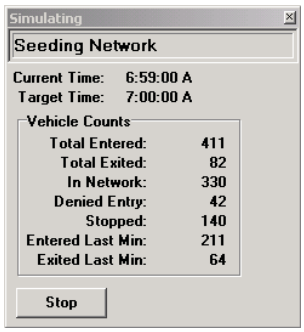
Loading Files

Select the File-Open button or the File→Open menu command to load a file. SimTraffic 7/8 uses Synchro 7/8 style *.syn files for data inputs.

If you are working with a file in Synchro, you can start SimTraffic by pressing the SimTraffic-Animation button or pressing [Ctrl]+[G].

Recording and Playback

Seeding Network



After a file is loaded, the network is seeded. Network seeding fills a network with vehicles, so that there will be vehicles in the network when simulation begins. The length of seed time can be changed with Options→Intervals-and-Volumes command.

Simulation Recording

In SimTraffic there are three ways to create traffic simulations. Simulations can be recorded and subsequently played back. Alternatively, simulations can be created while animating.

The Record-Simulation button or [Ctrl]+[E] will perform simulation and record information for animation, reports, and static graphics. The length of time recorded can be changed with the Options→Intervals-and-Volumes command.

The Simulate-While-Playing button ([F5]) will simulate traffic while animating (SimPlay). The SimPlay option is useful for quickly viewing traffic. Simulations created with SimPlay cannot be used for reports and static graphics.

In many cases, it is possible to change traffic volumes or signal timings and simulate while playing without re-seeding the network. This makes it possible to simulate many similar timing plans quickly. To change data without reseeding, it is necessary to start SimTraffic from Synchro.

Playback

The Speed-Control box shows the current speed and allows the user to change the speed quickly. Click on the center red bar to stop playback or SimPlay. Pressing [F2] will also pause playback or SimPlay.

The Stop Simulation button [F2] will stop the simulation playback.

Clicking on the right bars will play or SimPlay at 1/2x, 1x, 2x, 4x, and 8x speed. If simulation data is recorded, it will be played back, otherwise new simulation data will be SimPlayed. The simulation may not actually play at the full speed with a large network or on a slow computer. To speed animations, consider animating a small part of the network.

Refer to page 4-28 for advanced SimTraffic operation.

If you have coded a Synchro file, you have also created the inputs for SimTraffic. To begin the simulation and animation, you simply need to press a button.

By default, SimTraffic will seed for 3 minutes and record for 10 minutes. These are good values to use to get your model 'up and running'. To simulate to print reports, it is suggested that you record your model for 60 minutes to see the full impact.

A rule of thumb seed time is to look at the Arterial LOS Report from Synchro for all arterials in the network. Use the longest travel time value; convert this to minutes and multiple by 2. Use this as your SimTraffic Seed time.

HANDOUT

Clicking on the left bars will play in reverse at 8x, 4x, 2x, 1x, and 1/2x speed.

The Go-Back-in-Time-to-Beginning-of-Recorded-History button or [<] key returns to the start of recorded history.

The Frame-Reverse button or [-] key takes the animation back 0.5 seconds. SimTraffic simulates traffic at 0.1 s increments but only records traffic data at 0.5 increments. A frame is therefore 0.5 s.

The Frame-Advance button or [+] key takes the animation forward 0.5 seconds. SimTraffic simulates traffic at 0.1 s increments but only records traffic data at 0.5 increments. A frame is therefore 0.5 s.

The Skip-to-the-End-of-Recorded-History button or [>] key sets the animation at the end of recorded history.

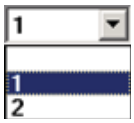
The Playback-Time box shows the starting and ending times of recorded history on the left and right sides. The center number indicates the current animation time. The needle in the playback time box can be dragged to quickly go to a specific time.

Multiple Simulation Runs

The Record-Multiple Runs button or [Ctrl]+[M] will perform and record a simulation on multiple runs. A dialog will appear allowing the user to select the number of runs to simulate and record and the starting random number seed. The random number seed will be incrementally increased by one for the simulated runs. For instance, 1, 2, 3, 4 and 5 if starting from 1 with 5 runs.

Recording your file with one random seed is much like watching your traffic in the street for 1 hour and saying this represents all days. Just like in the real world, random events can cause differences in simulation results. It is suggested that you record your model with 5 to 10 simulation runs to help reduce the variability in results.

The Run Number of Recorded History will allow the user to load a recorded history file if multiple runs have been performed. Choose the number of the run you would like to animate with the drop down list. The number will be the random seed number that was used. It is possible to have a blank value in the drop-down list. This indicates a simulation run without a run number extension.



The run numbers are used on the same input data and time intervals to get a statistical average of varied random seeds.

In the reports, the user is allowed to have the report generator average the results for some of all of the runs performed.

History Files

SimTraffic records the animation data into a history file. Normally this file has the same name as the *.syn file but has the extension hst. If you have recorded multiple runs (see above), the hst file will be formatted as filename-#.hst. The '#' will indicate the random seed number that was used during the recording.

This History file is preserved so that animations can be displayed later and reports can be created without re-seeding and re-recording.

Making Presentations with Prerecorded Data

If you are planning to make a presentation, it is helpful to have a *.hst file with the animations pre-recorded. To insure that the *.hst file is valid and does not require re-seeding, close SimTraffic and restart SimTraffic to verify that the history file can be loaded without re-seeding.

When copying files between computers or directories, be sure to copy the *.syn, *.sim, *.hst and image files (if appropriate) so that all data is transferred. The demo version can play but not record history files.

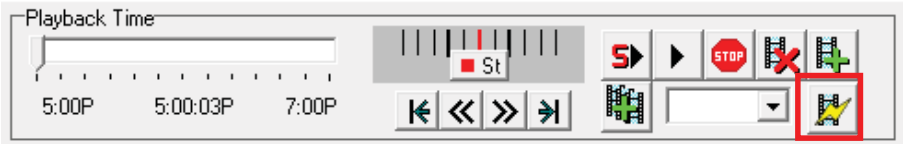
Sometimes the *.hst file may need to be destroyed or may require re-recording. The following actions can render a *.hst file invalid.

HANDOUT

- ✓ Changing data in the *.SYN file. Zoom settings are exempt.
- ✓ Changing any simulation options or parameters in SimTraffic. Map Settings and zoom positions are exempt.
- ✓ Changing the data files if volume or timing data is used.
- ✓ Use the SimTraffic-Animation button in Synchro to change data without re-seeding.

Screen Recorder in SimTraffic

A new feature to record the SimTraffic animation is now included. To create a video, choose the Video Recorder [VR] button on the upper-ride side of the SimTraffic toolbar.



After selecting the VR button, the **Video Recorder Settings** dialog will appear. The upper left of the dialog include **Predefined Settings**. You can select one of the three options for a larger or smaller file. The larger file will be larger in size, but will have a better video quality. The actual size of the video depends on the length of the recording. It is suggested that you try smaller formats first and move up to improve quality as needed.

The three options will use predetermined settings for **Screen Size, Frames per second,** choice of video (for local machine or web) and **Video Quality**. These values can be modified to meet the desired needs.

Once the settings are determined, use the [Select] button to browse to a directory and enter a filename. The format will be a Window Media Video (WMV) file. Finally, choose the [Generate] button to create your video.

It is possible to load multiple copies of SimTraffic to display multiple versions of a network at the same time. Choosing the **SimTraffic-Animation** button from Synchro will not start a second instance of SimTraffic; it simply loads the current file into the already started instance of SimTraffic.
Multiple instances of SimTraffic can be started by choosing the SimTraffic icon on the Windows Start bar.

Analyzing Part of a Network or a Single Intersection with SimTraffic

SimTraffic analyzes all intersections in a file or network. There is no provision for modeling part of a network or zone within a file.

To analyze part of a network, do the following:

1. In Synchro, select the desired intersection(s) on the map. Multiple intersections can be selected by dragging a rectangle around them.
2. Choose the File→Save-Part command.
3. Start SimTraffic from the Windows start bar and Open the sub-network file.

Map Settings

Use the command Options→Map-Settings to change the appearance of the map.

Map Zooming and Scrolling

To scroll around the map, choose the *Pan* button or press the [End] key. To deactivate, select the button again or press [Esc]. In addition, holding the mouse wheel button down will allow you to drag the map.

To view the map closer, choose the **Zoom-In** button or press [**Page Down**]. It may be necessary to scroll to put the map in the center of the **MAP** view first.

HANDOUT

To view more of the map, choose the **Zoom-Out** button or press [**Page Up**].

To view the entire map, choose the **Zoom-All** button or press [**Home**].

To view a specific section of the map, use the **Zoom-Window** button or press [**Ctrl**]+[**W**]. Then click on the upper-left corner of the viewing area. Then click on the lower-right corner of the viewing area.

To view the map at a specific scale, use the **Zoom-Scale** button. Then enter the desired scale to view the map in feet per inch (meters per inch). This command assumes 100 pixels per inch on your screen.

To return to the previous view, press [**Ctrl**]+[**Bksp**].

Signal Status

Click with the mouse in the middle of the intersection to display the status of an actuated or pretimed signal. Click in the Signal status window and press [delete] to close the window.

Vehicle Status

Click with the mouse on a vehicle to display the status of a vehicle. Vehicle status can be used to help explain vehicle behaviors. Click in the Vehicle status window and press [delete] to close the window.

Reports, Graphics, and MOEs

To create a report select the **File→Create-Report** command. Select the reports desired. The following sections describe the reports available.

Simulation Summary Report

The Simulation Summary report lists the intervals and their properties, and some overall statistics about the number of vehicles serviced.

The summary report can be used to keep track of the intervals simulated, the volume adjustments made, and the timing plan(s) used.

Measures of Effectiveness

Total Delay is equal to the travel time minus the time it would take the vehicle with no other vehicles or traffic control devices.

Delay per Vehicle is calculated by dividing the total delay by the **Number of Vehicles**.

The **Number of Vehicles** is not a fixed number because some vehicles are in the area analyzed before the interval begins and some are in the area after the end of analyzed after the interval ends.

The **Stopped Delay** is the sum of all time slices where the vehicles are stopped or traveling at less than 10 ft/s (3 m/s). Normally the Stopped Delay will be less than the total delay. Stopped delay also includes all time spent by denied entry vehicles while they are waiting to enter the network.

Stop Delay/Vehicles is calculated by dividing Stop Delay by the Number of Vehicles.

The **Total Stops** is a count of vehicle stops. Whenever a vehicle's speed drops below 10 ft/s (3 m/s) a stop is added. A vehicle is considered going again when its speed reaches 15 ft/s (4.5 m/s).

Stops /Vehicles is calculated by dividing the number of Stops by the Number of Vehicles.

Remember, Synchro results will vary from SimTraffic. Synchro is macroscopic, deterministic model and SimTraffic is a stochastic simulation model.

HANDOUT

The **Travel Distance** is simply a summation of the vehicle distance traveled. This distance includes the curve distance within intersections.

The **Travel Time** is a total of the time each vehicle was present in this area. The travel time includes time spent by vehicles Denied Entry.

The **Average Speed** is calculated by dividing Total Distance by Total Time. Average Speed is weighted by volume and includes stopped time and denied entry time. The time use in calculation for Average Speed does not include time spent by denied entry vehicles while they are waiting to enter the network. Average speed may thus be higher than Total Time divided by Total Distance.

Fuel Used is calculated with the fuel consumption tables . The fuel used in each time slice is determined by the vehicle's fleet (car, truck, or bus), speed, and acceleration.

The **Fuel Efficiency** is calculated by dividing the Total Distance by the Fuel Used.

Emissions data are calculated with the vehicle emission tables. The vehicle's speed and acceleration determine the emissions created in each time slice. There is no emission tables available for trucks and busses. SimTraffic assumes trucks and busses emit exhaust at three times the rate of cars.

Vehicles Entered and **Vehicles Exited** is a count of how many vehicles entered and exited the link or area in the interval(s). If this is a network or arterial summary, the Vehicles Entered and Vehicles Exited do not count a vehicle moving from one intersection to the next within the arterial or network. The Entered and Exited counts for a network or arterial will thus be less than the sum of the counts from each intersection.

The **Hourly Exit Rate** is the Vehicles exited at an hourly rate. If the intersection is above capacity and the input volume is not constrained upstream, this value might be used as the capacity for this movement

Denied Entry is a count of vehicles that are unable to enter a link due to congestion. Denied Entry includes external links and mid-block vehicle sources. The report lists the number of vehicles denied entry at the start and end of the period. This is useful to see if congestion is getting worse or better. Denied Entry can also be used to determine the **Network Throughput**. In a congested network lower values of Denied Entry indicate increased throughput.

Density is the average distance per vehicle over the simulation period. It is only available by-lane, and by-approach but not by-movement; multiple movements can share a lane.

Ocupancy is the average number of vehicles in a lane or approach over the simulation period.

In Synchro, the queue length is calculated by integrating the arrival pattern of the arriving vehicles and determining the height of the shape for the 50th and 95th percentile volume levels. Basically, this would be similar to entering data into an equation to get a resulting queue length (this is true with any macroscopic model). This equation is NOT limited by the turn pocket length that is coded. For instance, say the turn pocket in the above graphic is 250'. It would be possible that the Synchro queue that is reported is greater than 250'.

In SimTraffic, the queue length reported for a movement IS limited by the turn pocket length, just like in the real world. SimTraffic simply observes the maximum queue. So, if you have a left turn pocket of 250', then you could not achieve a SimTraffic left turn queue of greater than 250'. Any spillover from the left turn pocket would be reported in the adjacent lane queue length.

Queuing and Blocking Report

The Queuing and Blocking report gives information about the maximum queue length for each lane and the percentage of time critical points are blocked.

A vehicle is considered queued whenever it is traveling at less than 10 ft/s (3 m/s). A vehicle will only become “queued” when it is either at the stop bar or behind another queued vehicle.

The **Maximum Queue** is the maximum back of queue observed for the entire analysis interval. The **Average Queue** is average of all the 2 minute maximum queues.

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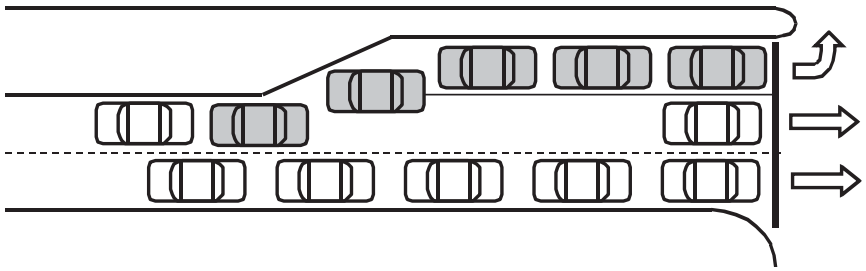
A standard deviation is also calculated using the sum of squares for each 2 minute interval. The 95th Queue is equal to the Average Queue plus 1.65 standard devidations. The 95th Queue is not necessarily ever observed, it is simply based on statistical calculations.



Upstream Block Time is the proportion of time that the upstream end of the lane is blocked. The **Queuing Penalty** is a rough measure of how many vehicles are affected by the blocking. **Storage Bay Distance** is the length of a turning bay. **Storage Block Time** is the proportion of time that a lane is queued at the top of the storage. **B##** is a column that is not always present and is used for reports on the queue for a bend link.

Actuated Signals, Observed Splits Report

The actuated signal report displays information about the actual times observed in actuated signals. This report can be used to show how an actuated signal will perform with detailed modeling. This report can be helpful to compare the affects of adjusting gap settings, detector layouts, recalls and so on.

Static Graphics

To display static graphics, choose the **Graphics→Show-Static-Graphics** command. Select the display desired.

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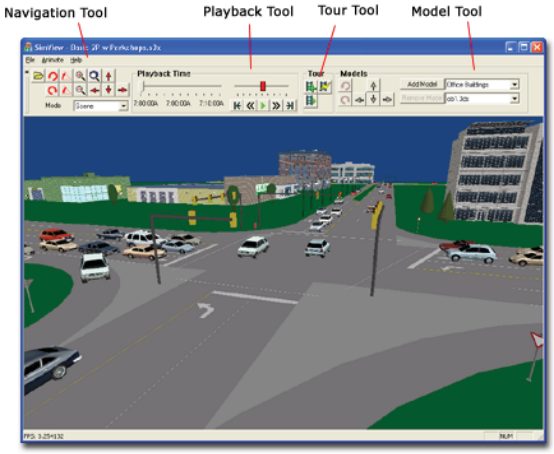
3.7 3D Viewer

SimTraffic can create a 3D file which can be viewed with the Trafficware 3D Viewer. The three primary modes of the viewer for playback of SimTraffic data in a 3D environment include scene, ride, and track. The ability to create scenery to enhance the default background is also available in the 3D Viewer.



To create the 3D file, use the command **Animate→Create 3D Graphics File**. A file with an S3D extension will be created in your project directory.

Use the **3D Viewer** button to launch the 3D Viewer application. Refer to Chapter 25 of the Synchro Studio User Guide for full details on using 3D Viewer.

A Scene is a three-dimensional rendering of a SimTraffic network. A scene is generated when the user creates a 3D graphics file using SimTraffic.

Create Digital Videos

3D Viewer can be used to create digital video in .AVI format. Digital video can then be copied to other computers for playback, even if 3D Viewer is not installed.

3D Viewer generates digital video are based on "Tours". Tours can then be used as input to the video generation process.

Add Buildings and Scenery

Users can add buildings and scenery to 3D Viewer scenes to create realistic simulations. To add a building, tree or other model, navigate to the location in the scene near the point where the model is to be placed. Select the model from a model list.

Changing the Size of a Model

To change the size of a selected model object, hold "Shift" key and rotate the mouse wheel. The model object will be proportionally increased or diminished. To make the size change slower, hold "Ctrl" key.

Also, you can change length, width and height of a selected object using Models pane by editing L, W and H values.

Adding a Custom Model in 3ds Format

In the "Models Preview" window, there is a button "Import Models". You can browse for an existing .3ds file to include in the list of the "Custom Models" category.

A New Button for the Tour Panel – Filming

The **Filming** button becomes enabled in the record mode and has the two states – "pause filming" and "resume filming".

HANDOUT

4. LEVEL II

4.1 Calculations

In this section, some of the calculations used by Synchro are discussed.

Delay Calculations

In Synchro, there are three (3) options for reporting the signalized intersection delays. This includes:

- ✓ The Synchro Control Delay (Percentile Methods);
- ✓ The 2000 HCM Signals Delay, and;
- ✓ The 2010 HCM Signals delay.

The Delay that is shown in the **TIMING** Settings window and the 'Int:' reports are the Synchro Control Delays.

The 2010 HCM Signal Delays are shown in the **HCM 2010** Settings window and in the Reports. This window and report provides full implementation of the 2010 HCM methods.

To see the 2000 HCM delay, create an HCM 2000 Signals Report (use the command **File→Create-Report** and choose the 'HCM 2000 Signals' in the Select Reports window). This report provides a full implementation of the 2000 HCM methodology.

The following sections will further define these calculations.

Important: When you input the Total Splits in the TIMING Settings, these are the Maximum Splits for any actuated movement. The time used is actually based on five Percentile green times that vary based on the flow level.

For example, assume you have phase 1 EBL that you entered a Maximum Split of 20 seconds. If the movement is actuated, it may not receive this full 20 seconds. Look at the Actuated Effective Green time to see the actual time used in the calculations. If you would like Synchro to use this full 20 seconds, then set the Recall to Max.

HCM (2000) Signals Delay Calculation

When you use the command **File→Create-Report** and choose the 'HCM 2000 Signals' in the Select Reports window, you will get a year 2000 HCM Signals report (uses the 2000 HCM Methods). For these methods, one cycle length is used to represent the analysis period and the user is required to input actuated green times. Synchro calculates this actuated green time for the user based on the average of fiver percentile greens (defeined below). The g/c ratio, v/c ratio and delay calculations are based on the actuated green times and cycle length.

HCM (2010) Signals Delay Calculation

When you use the command **File→Create-Report** and choose the 'HCM 2010 Signals' in the Select Reports window, you will get a HCM Signals report. Or, you can navigate to the **HCM 2010 Settings** window. This is based on the methods of the year 2010 HCM. The 2010 HCM methods have a computational engine that will calculate an actuated cycle length and actuated effective green times. The g/c ratio, v/c ratio and delay calculations are based on this actuated green times and cycle length.

The year 2010 HCM is no longer just a printed manual. Volume 4 of the HCM includes electronic materials. Within this volume is a computational engine that performs the calculations. This includes a method to calculate an effective green for actuated movements.

Synchro Control Delay (The Percentile Delay Method)

In Synchro, the delay shown in the **TIMING** Settings window is the Synchro Control delay. If you create a report other than the HCM Signal Reports, the delay shown will be the Synchro Control delay. This is based on the Percentile Delay method. Basically, the Percentile Delay method calculates the delay for five percentile volume levels (10th, 30th, 50th, 70th and 90th). The delay result is then the weighted average of the five percentile scenarios.

Percentile Scenarios

To account for variations in traffic, Synchro models traffic flow under five percentile scenarios, the 90th, 70th, 50th, 30th, and 10th percentile scenarios based on a Poisson distribution.

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If 100 cycles are observed, the 90th percentile cycle will represent the 10 busiest cycles. Each of these scenarios will represent 20% of the cycles actually occurring.

The traffic volumes for each scenario are adjusted up or down according to the following formulas.

The expected number of vehicles, λ, is the hourly flow rate divided by the number of cycles per hour.

$$\lambda = v * \frac{C}{3600}$$

$$v = \text{Volume (vph)}$$
$$C = \text{Cycle Length (s)}$$

The variance, or standard deviation, in traffic is the square root of the expected number of vehicles for a Poisson arrival.

$$\rho = \text{Sqrt}(\lambda) = \text{standard deviation in expected arrivals per cycle}$$

The expected number of vehicles for a given percentile can be calculated using a Poisson distribution. A Normal Distribution can be used if the expected number of vehicles is greater than 6. This gives the formula:

$$vP = (\lambda + z\rho) * \frac{3600}{C}$$
$$C = \text{Cycle Length (s)}$$

z is the number of standard deviations needed to reach a percentile from the mean. It can be determined from this table.

Percentile	Z
10	-1.28
30	-0.52
50	0
70	0.52
90	1.28

The simplified formula to determine adjusted volumes is thus:

$$vP = v + \left[z * \sqrt{\left(v * \frac{C}{3600} \right)} \right] * \frac{3600}{C}$$
$$\text{with } vP \geq 0$$

Using five scenarios instead of one has several advantages. Even though an approach is below capacity, it may be above capacity for the 90th percentile traffic. By modeling the 90th percentile traffic, it is possible to better model nearly saturated intersections.

Using multiple scenarios allows actuated signals to be modeled under multiple loading. The complex operation of actuated signals will vary under the five scenarios and give a range of expected green times over the course of an hour.

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Refer to the Calculations Handout 'Percentile Flow'. Also, refer to the sample file 'C:/Class Files/Level 2/01 Calculations.xls'.

Actuated Signal Considerations

To estimate the delay for actuated signals, it is necessary to determine how skipping and gapping behavior will change their timings. These actuated timings are then used with the Percentile Delay formulas.

The key to determining actuated behavior is to predict if each phase will be skipped and when each phase will gap out. Once these behaviors are determined, the green and red times from the actuated signals can be used to model delays.

Determine Skip Probability. Synchro assumes a phase will be skipped if there is a greater than 50% chance of zero vehicles during red time.

Determine Queue Clear Time. This is the startup lost time plus the service time for any vehicles that arrived during red plus vehicles arriving during the clearance time.

Determine Time to Gap-Out. This is the time from when the queue clears until there is a 50% chance of gap-out**.** It is dependent on the detector placement and vehicle extension time**.**

Percentile Delay Summary

The basic premise of the Percentile Delay Method is that traffic arrivals will vary according to a Poisson distribution. The Percentile Delay Method calculates the vehicle delays for five different scenarios and takes a volume weighted average of the scenarios. The five scenarios are the 10th, 30th, 50th, 70th, and 90th percentiles. It is assumed that each of these scenarios will be representative for 20% of the possible cycles.

- ✓ For each scenario, traffic for each approach is adjusted to that percentile.
- ✓ If the signal is actuated or semi-actuated, the skipping and gap-out behavior for these traffic conditions are used to determine the green times for each scenario.
- ✓ If the signal is in coordination, an arrivals flow pattern is calculated to account for the effects of coordination.
- ✓ Delays are calculated using the adjusted volumes and calculated green times.
- ✓ Estimating actuated operation or coordination arrivals may require that the calculations be performed iteratively.
- ✓ If the signal is near-saturation or above saturation, additional time will be added to account for vehicles carried over between cycles.

How Do the Delay Methods Compare?

As discussed above, there are three options for reporting the delay in Synchro. These three methods are macroscopic, deterministic methods all based on the methods of the Highway Capacity Manual. In addition, SimTraffic can provide a microscopic simulation result.

The results between the methods can vary quite drastically (macro vs. micro differences were discussed in early portions of the class). To illustrae some differences, consider a variety of case studies. Open the file '00 HCM Methods Compared.SYN'.

Case 1: Isolated Pretimed Signal

For this example, refer to node 1 in the referenced file. This interseciton is isolated, operates with a pretimed signal, uses NEMA phasing convention and includes protected lefts for all

HANDOUT

The simulation results show in the tables are the averages of 10 simulation runs. Each run was seeded for 10 minutes and recorded for 60 minutes.

Simulation models do not include a LOS measurement. The SimTraffic LOS shown in the tables uses the HCM criteria for Control Delay. It should be recognized that SimTraffic does not report Control Delay, but movement Delay/Vehicle. The LOS show is for illustration purposes only.

The 2010 HCM results only show the approach delays. This is due to the format of the HCM 2010 report from Synchro. This report is based on the HCM computational engine spreadsheet.

four approaches. In addition, the storage lengths are generally adequate and blocking problems are not expected to be significant.

The table below summarizes the delay results for the three macroscopic methods and from SimTraffic as an illustration.

Control Type: Pretimed (Node 1)

Method	Movement												Total	
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	Delay	LOS
Synchro	42.6	24.2	4.7	69.7	25.4	6.3	44.4	46.7	9.4	93.8	40.3	8.8	31.2	C
2010 HCM Report	26			34			45			55			33.4	C
2000 HCM Report	41.7	23.9	16.1	67.7	25.1	19	43.8	45.7	30.2	90.9	39.7	30.4	32.7	C
SimTraffic	49.4	29	22.4	87.3	24.7	12.8	48.5	40.7	19.3	80	37.8	14.5	34.9	C

As can be noted, the results for each scenario match closely. This is expected since the green times are fixed, there is no coordination and no potential storage blocking issues.

Case 2: Isolated Fully Actuated Signal

For this example, refer to node 2 in the referenced file. This interseciton is isolated, is fully actuated, uses NEMA phasing convention and includes protected lefts for all four approaches. In addition, the storage lengths are generally adequate and blocking problems are not expected to be significant.

Control Type: Act-Uncoord (Node 2)

Method	Movement												Total	
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	Delay	LOS
Synchro	45.4	26.1	5	57.9	24.2	6.4	42.6	46.5	9.6	74	31.1	8.2	29.9	C
2010 HCM Report	23			25			38			36			26.5	C
2000 HCM Report	41.6	26.6	17.1	51.4	23.4	18.4	51	33.6	26.3	61.3	26.3	23.4	29.4	C
SimTraffic	50.7	29.3	23.2	68.4	22.7	12.2	48.5	43.1	21	102	34.7	15.9	34.3	C

The results for the study still show relatively close values for each method. There is a little more discrepency and that can mostly be associated with the effective green times.

Case 3: Actuated-Coordinated Signal in a System

For this example, refer to node 3 in the referenced file. This interseciton is located in a system, is actuated-coordinated, uses NEMA phasing convention and includes protected lefts for all four approaches. In addition, the storage lengths are generally adequate and blocking problems are not expected to be significant.

Control Type: Act-Coord (Node 3)

Method	Movement												Total	
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	Delay	LOS
Synchro	34.2	10.5	1	60.8	15.6	2.2	44.2	52.9	9.7	75.8	33.4	8.1	22.5	C
2010 HCM Report	33			37			41			42			36	D
2000 HCM Report	31.5	11.5	2.8	54.6	16.7	6.8	54.3	46.9	31.2	42.1	29.2	25.9	22	C
SimTraffic	34	22.6	14.7	59.5	19.6	11.9	49	44.9	19.6	68.5	32.8	14.4	27.9	C

In this example, the results are beginning to vary more significanlty when comparing the 2010 methods to the Synchro and 2000 HCM results. This is mostly associated with how each method handles vehicle arrivals. This is discussed in more detail later.

Case 4: Actuated-Coordinated Signals, Closely Spaced

For this example, refer to node 4 in the referenced file. This interseciton is located in a system, is actuated-coordinated, uses NEMA phasing convention, includes protected lefts for all four approaches and is closely spaced to node 18.

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Control Type: Act-Coord, Close Spaced Intersections (Node 4)

Method	Movement												Total	
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	Delay	LOS
Synchro	58.2	245	<	61.4	206	<	44.6	48.8	<	164	31.1	<	167.6	F
2010 HCM Report	38			32			44			46			37.9	D
2000 HCM Report	52.4	36.1	<	50.7	29.6	<	54.3	37.2	<	81.4	29.1	<	37.7	D
SimTraffic	380	317	91.1	54.3	23	17.1	44.4	48.1	39.6	3250	2253	2175	356	F

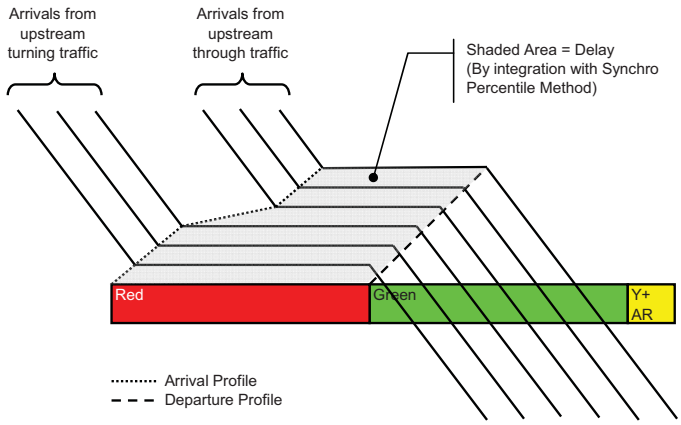
The results now show drastic differences. Synchro does include a queue delay measurement and the HCM methods do not. SimTraffic shows a much greater delay given the compounded nature of the congestion.

Summary of Synchro's Macro Model Differences

Item	Synchro	HCM 2000 Report	HCM 2010 Report
Percentile Method	Synchro uses a Poisson distribution to determine five representative volume levels (10th, 30th, 50th, 70th and 90th Percentiles)	Uses a single volume analysis. This single volume would be the same as Synchro's 50th Percentile Volume.	Uses a single volume analysis. This single volume would be the same as Synchro's 50th Percentile Volume.
Actuated Green Inputs	In Synchro, the user inputs the actuated parameters such as minimums and maximums. The Actuated Green time is calculated for five percentile scenarios.	This will use the average of Synchro's five Percentile green times. Note: in traditional HCM 2000 analysis, the user was required to input the actuated green times.	For fully actuated conditions, the effective green times are determined by the HCM 2010 computational engine. The HCM comp engine does not currently provide effective green times for actuated coordinated signals. Synchro will use the effective green times it uses for the 2000 HCM methods.
Dual Ring Control	All three methods use dual ring, NEMA phasing. However, traditional 2000 HCM methods use single ring operation.		
Progression Factor (PF) (see note 1)	Synchro explicitly calculates the PF based on upstream arrivals (via integration, see note 1)	The HCM Report will calculate the PF from Synchro Percentile integration. This is the Percentile Delay Coordinated divided by the Percentile Delay Uncoordinated.	Currently, the HCM comp engine only considers isolated intersections. Synchro will calculate a Platoon Ratio and an Upstream Filtering Factor.
Right Turn on Red (RTOR) (see note 2)	Synchro calculates the RTOR and makes a saturation flow adjustment. This will increase the capacity for the movement.	The HCM methods subtract the RTOR volume from the analysis.	
Queue Delay	Synchro includes a component for Queue Delay.	The HCM methods do not include a Queue Delay component.	
Complex Geometry	Synchro can model intersections with up to 6 legs (8 in some cases).	The HCM methods are limited to 4 legs intersections.	

HANDOUT

1. **Progression Factor**. In Synchro, there is no progression factor or arrival type factor. The delays are explicitly calculated by integrating the arrival patterns over the departures (saturation flow). For the HCM reports, Synchro calculates a PF.



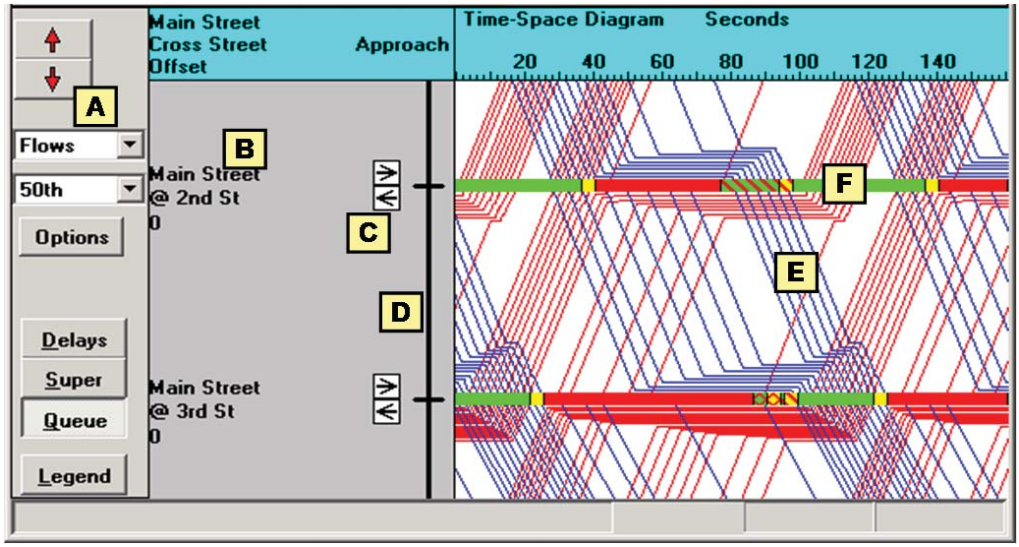
2. **RTOR**. In Synchro, the RTOR is a saturation flow increase. For the HCM methods, the RTOR is a volume reduction. These RTOR vehicles that are excluded are often low delayed vehicles so the only ones left are those that are getting delayed. Also, the result shown is the Delay per Vehicle. Since the HCM method has a higher aggregate delay, and a lower number of vehicles in the denominator, the delay per vehicle will be higher.
3. **Queue Delay**. Synchro adds delay caused by spillback and starvation between adjacent, closely spaced intersections. The HCM methods do not account for spillback or starvation. Note: Nether method accounts for spillback out of turn pockets.

HANDOUT

4.2 Time Space and Platoon Dispersion Diagrams

Time-space diagrams can be used to see graphically how traffic flows between intersections. To view a time-space diagram, first click on the desired intersection or the desired link to select it, then press the ***Time-Space Diagram*** button or the [F7] key.

The Parts of a Time-Space Diagram



Synchro's time-space diagrams display time along the horizontal axis and distance along the vertical axis.

The following information summarizes each part of the time-space diagram above.

A Toolbar- These buttons change the views of the **TIME-SPACE DIAGRAM** window.

B Street Names and Offsets- These are the street names of the intersection shown. The top name is the name of the street with the time-space diagram being shown. The bottom name is the name of the cross street. Underneath the street names is the intersection offset. The offset is referenced to the reference phase even if it is not one of the approaches in the diagram.

C Direction Icon- These icons indicate the direction of the street in question.

D Street and Intersection Diagram- The vertical line represents the street with the time-space diagrams. The horizontal lines are crossing streets.

E Traffic flow lines or Traffic Density Diagram- The diagonal and horizontal lines show traffic flow.

F Timing Bands. The red, green, and yellow bands indicate the phase of the signal for each part of the cycle. The green bands for an actuated signal may start or end early. The times shown are actuated times and this represents the phases gapping out early. Select [Max] to show maximum green times.

Select the ***Legend*** button to display a color-coded legend. The legend shows the color for the flow lines and the through and left timing bands. If the [Queue] button is selected, the legend will include queue interaction color-coding.

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Time-space and flow diagrams are useful to visualize the traffic flows along an arterial route. They can also be used to fine-tune your offsets.

Time-Space Options

Scrolling

To scroll or move the time space diagram vertically, use the arrow buttons, the arrow keys, or by clicking and dragging on the diagram (away from the timing bands).

Bandwidth option

The bandwidth option shows arterial bandwidths. Bandwidth is the part of the cycle that allows the vehicles to go through all intersections without stopping. Synchro shows both arterial bands and link bands.

Vehicle Flow Option

This diagram also shows the speed and position of the vehicles. Each line represents one or more vehicles.

Percentile Options

These scenarios represent 90th, 70th, 50th, 30th, and 10th percentile cycles for the hour for which volume data is given. If you looked at 100 cycles, the 90th busiest cycle is the 90th percentile. The 50th percentile represents average traffic conditions.

Show Delays

To show the **average delays** for each movement and the intersections overall, push in the ***Show Delays*** button.

Show Super Saturated

When this option is enabled, lane groups operating above capacity are shown with their queues filled at the beginning of green. When this option is off, the time-space diagram assumes that all queues are cleared at the end of green

Time-Space Diagram Options

The command **Options→Time Space Diagram** is used to change the scale of the diagrams, change the flow line colors and turn on or off some of the flow directions or flows to left turns.

Time and Distance Scale

For the time scale, enter a number between 16 and 96.

Enabling Flow Lines and Changing their colors.

Viewing traffic flows for four movements simultaneously can be a bit overwhelming. There are options to limit the movements shown simultaneously.

Adjusting Splits and Offsets

To change an offset for any phase, click and drag on the timing bands away from any phase boundaries. The cursor will change into a hand shape before and during offset adjustment.

To change a split for a phase, click and drag on the timing bands at a phase boundary. The cursor will change into a splitter shape before and during split adjustment. This feature changes the maximum splits.

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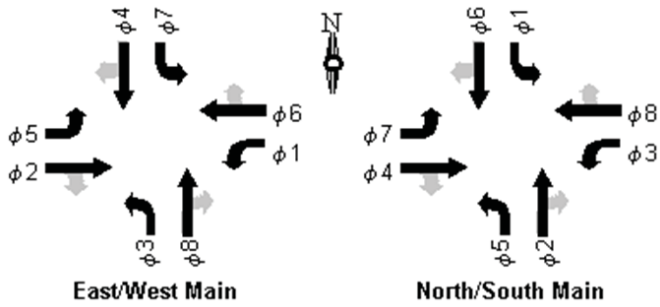
4.3 Advanced Inputs

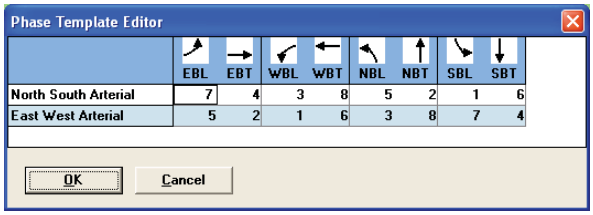
In this section, some of the advanced input features of Synchro and SimTraffic will be discussed.

Phase Templates

Phase templates allow phase numbers to be set automatically. Below is the Synchro default.



In general, changing the template will not have an impact on the results shown in Synchro. However, the measures could change if you are in a coordinated system and you do not update your coordinated phases for the modified template



Phase Template Editor

	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
North South Arterial	7	4	3	8	5	2	1	6
East West Arterial	5	2	1	6	3	8	7	4

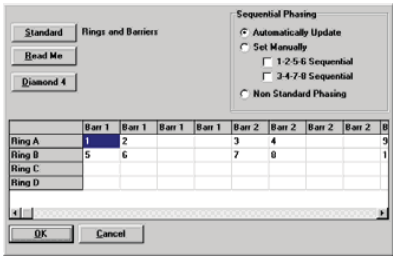
OK Cancel

To edit the phase templates, use the menu command Options→Phase-Templates→Edit-Template-Phases.

Enter phase numbers for each through and left movement. Local standards may have the phases mirrored from Synchro's defaults. Use default phase templates to setup phase numbers matching the agencies standard phasing scheme.

Ring and Barrier Designer

To activate, use the menu command **Options→Ring-and-Barrier Designer**.



The Ring and Barrier Designer allows up to 32 phases to be entered in one of 64 fields. This allows for the modeling of complex phasing strategies. Phase numbers are entered into the appropriate barrier, ring and position (BRP) fields in the four rings and four barriers.

The following displays the default phase assignments within the Ring and Barrier Designer. The values in the table can be modified to meet your particular needs. To revert back to the default phasing layout, select the ***Standard*** button.

	Barrier 1				Barrier 2				Barrier 3				Barrier 4			
Ring 1	Phase 1	Phase 2			Phase 3	Phase 4			Phase 9	Phase 10			Phase 11	Phase 12		
Ring 2	Phase 5	Phase 6			Phase 7	Phase 8			Phase 13	Phase 14			Phase 15	Phase 16		
Ring 3																
Ring 4																

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When to use:

- ✓ Group Control (Multiple intersections on one controller)
- ✓ 5 or more legs
- ✓ Single ring controller, more than 4 phases
- ✓ Diamond interchange
- ✓ More than 9 phases

Not needed for:

- ✓ Split phasing
- ✓ Lagging phases
- ✓ Standard 8 phase controller
- ✓ Single ring controller up to 4 phases
- ✓ 8 phase controller + 9
- ✓ Many two intersection configurations

The rules to consider for the Ring and Barrier Designer are:

A **ring** is a term that is used to describe a series of conflicting phases that occur in an established order. Phases from any ring are sequential and cannot time with the other phases within the ring.

A **barrier** (compatibility line) is a reference point in the preferred sequence of a multi-ring controller unit at which all rings are interlocked. Barriers assure there will be no concurrent selection and timing of conflicting phases for traffic movements in different rings. All rings cross the barrier simultaneously to select and time phases on the other side.

A phase within a given ring can operate with any phase in any other ring within the same barrier. The graphic below illustrates the 64 positions allowed by Synchro. The number, such as 111, shown in the box indicates the Barrier-Ring-Position (BRP). So, 123 indicates barrier 1, ring B, position 3.

	Barrier 1				Barrier 2				Barrier 3				Barrier 4			
Ring A	111	112	113	114	211	212	213	214	311	312	313	314	411	412	413	414
Ring B	121	122	123	124	221	222	223	224	321	322	323	324	421	422	423	424
Ring C	131	132	133	134	231	232	233	234	331	332	333	334	431	432	433	434
Ring D	141	142	143	144	241	242	243	244	341	342	343	344	441	442	443	444

So, given the rules, the phase placed in 111 MUST be allowed to operate with a phase in 121, 122, 123, 124, 131, 132, 133, 134, 141, 142, 143 and 144.

HANDOUT

Example - Twice Per Cycle Left Turns Example

For this example, refer to the file 'C:\Class Files\Level 2\03a Twice per cycle left turns.SYN'.

One problem often experienced during long cycle lengths is the situation where a queue in a left-turn lane backs up into a through lane and reduces the capacity of the through movement. One option is to use a "Twice Per cycle Left-Turn" (TPCLT) to reduce this left-turn "spill-over" problem. During TPCLT, a protected left-turn phase is serviced twice per cycle as a leading and lagging left-turn that minimizes the blockage problem for the lagging through movement.

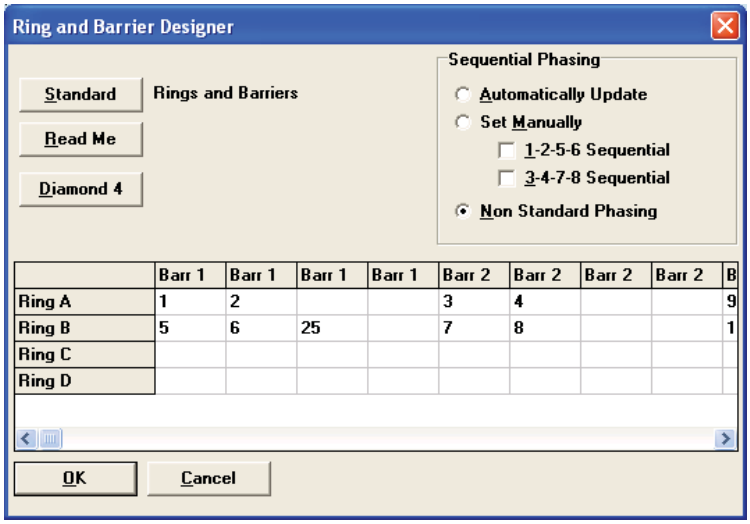
Keep the ring rules in mind. For the design of this example, ring B will service phase 5, 6 then 15. Phase 5, 6 and 15 MUST be allowed to operate with phase 1 and/or 2 without conflicts since all of these phases are in barrier 1.

TPCLT Operation

This operation differs from conditional-service that only allows a protected left-turn phase to be re-serviced if the opposing through movement gaps out. TPCLT is typically used during congested periods when all phases tend to max out. For this example, the desired TPCLT sequence is as follows:

80" cycle / EBL is the Twice Per Cycle Left-Turn (TPCLT).

In Synchro, you would create dummy phase (call it phase 25) that operates in Ring B, barrier 1 as show in the Ring and Barrier Designer below.



	Barr 1	Barr 1	Barr 1	Barr 1	Barr 2	Barr 2	Barr 2	Barr 2	B
Ring A	1	2			3	4			9
Ring B	5	6	25		7	8			1
Ring C									
Ring D									

Next, it is just a matter of specifying that the EBL phase operates during phase 5 and phase 25. To do this, enter a 5 then a 25 (separated with a space, comma or '+' symbol) in the Protected Phases row for the EBL.

Notice that the left-turn is now serviced twice per cycle using phase 5 and 25. The resulting Splits and Phasing diagram is as follows (**03b Twice per cycle left turns. SYN**):

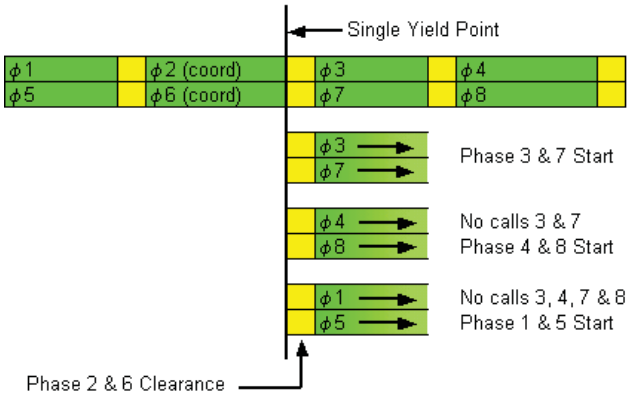
HANDOUT

The Yield Point setting is found in the Offset Setting box in the **TIMING** Settings.

Yield Points

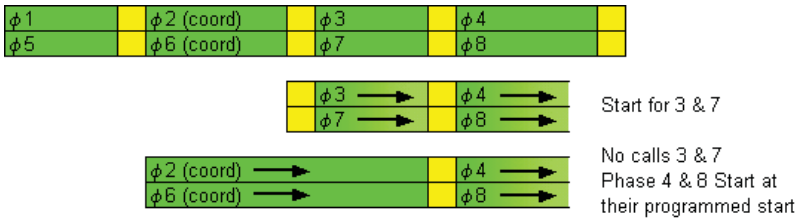
The Yield Point affects when the Coordinated Phases will "yield" to side street phases. This setting affects whether there is a single yield point for all phases; or multiple yield points.

The Figure below illustrates how a **single** yield point works. The main street phases have a single scheduled end time. If the next up phases have no calls, the other phases start at this point. If there are no calls for any of the phases 3, 7, 4 and 8; phases 1 and 5 can start early and the signal will return to the main street phases sooner.



Here are some notes about Synchro's implementation of Yield Point. Synchro models flexible yield points the same as single yield points. This will be equivalent except for when the 1st up actuated phases are low volume. With By Phase yield points, Synchro models a single yield point for each barrier.

The next figure illustrates how yield point **By Phases** works. The main street phases stay on until the scheduled start time of a conflicting phase. If phases 3 and 7 have no calls, the signal will not yield to phases 4 and 8 until their scheduled start times.



Flexible yield points allow the signal to yield any time between the single point and the phases scheduled start time. Flexible Yield Points can be useful with low volume side streets; the side streets have a wider range of time to yield the signal.

Using a Single Yield Point in conjunction with Fixed Force Off? makes the most time available for side street phases. By Phase can be helpful when providing coordination to side street phases. It is sometimes possible for the phase to be skipped because its yield time occurs before the platooned traffic arrives.

With modest amounts of traffic on one of the next up phases (phases 3 and 7 in the above examples), the signal will usually yield at the first available point and act like the single yield point. The other options are more applicable for lower volume side phases (200 vph or less).

The Yield Point is closely related to Fixed Force Off?, and **Actuated Main street** phases.

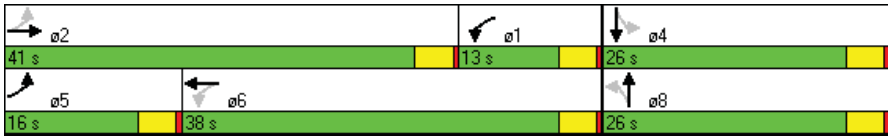
If the main street phases are coordinated, use a single or flexible yield point. Otherwise the main street phases will not yield early. The exception being for lead-lag phasing.

HANDOUT

Coordinated Recall

Coordinated Maximum (C-Max): Used with coordinated signals only. This option is available for phases selected as the reference phase in the Offset Settings. Phase shows for its maximum time starting at its scheduled start time.

Coordinated Minimum (C-Min): Used with coordinated signals only. This option is available for phases selected as the reference phase in the Offset Settings. Phase shows for its minimum time starting at its scheduled start time. Coordinated movements must have detectors. No affect with By Phase yield points except with lead-lag phasing.



Dual Entry

Dual Entry can be set to Yes or No for the given phase.

Select Yes to have this phase appear when a phase is showing in another ring and no calls or recalls are present within this ring and barrier.

Normally, even phases are set to Yes and odd phases are set to No. **Recall** has priority over dual entry. Below are examples for a typical eight phase, dual ring controller.

Examples:

Phases	1	2
Dual Entry	No	Yes
Recall	None	None

If there are no calls on phases 1 or 2, phase 2 will show when phase 5 or 6 is showing.

Phases	1	2
Dual Entry	No	Yes
Recall	Min	None

If there are no calls on phases 1 or 2, phase 1 will show when phase 5 or 6 is showing.

Phases	1	2
Dual Entry	No	No
Recall	None	None

If there are no calls on phases 1 or 2, no phase from this ring will show when phase 5 or 6 is showing.

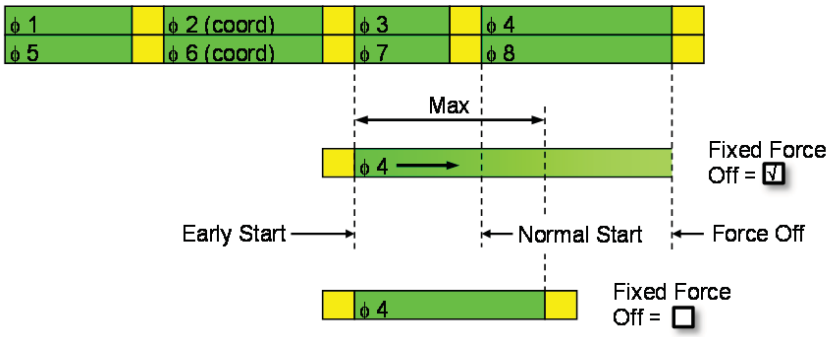
HANDOUT

Set Fixed Force Off to Yes to give more time to side streets, set Inhibit Max to No to give all extra time back to the main street.

Fixed Force Off?

Used for Actuated-Coordinated signals only. When Yes, a non coordinated phase can show more than its maximum time when it starts early.

In the figure below, Phase 4 can start early due to phase 3 being skipped. With Fixed Force Off? set to Yes, phase 4 can use all of phase 3's unused time. Otherwise this time would revert to the main street phases



The amount of time available for side street phases and their starts can also be manipulated by the Yield Point and using **Actuation for the Coordinated phases.**

The cluster editor is intended for use with closely spaced intersections. The advantage to operating multiple intersections with one controller is that phases at the intersections are controlled by barrier and phase positions, not by an offset. With an offset relationship, you may experience 'early release' which may be undesirable with close intersections.

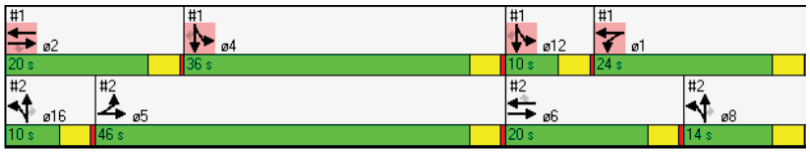
Cluster Editor

To activate, use the menu command **Options→Cluster-Editor**.

The **Cluster Editor** allows multiple intersections to share one controller (Group Control). This is often used in conjunction with the **Ring and Barrier Designer**.

Click on map to add or remove intersections from the cluster.

Each intersection has a color associated with it in the **Splits and Phasing diagram**.



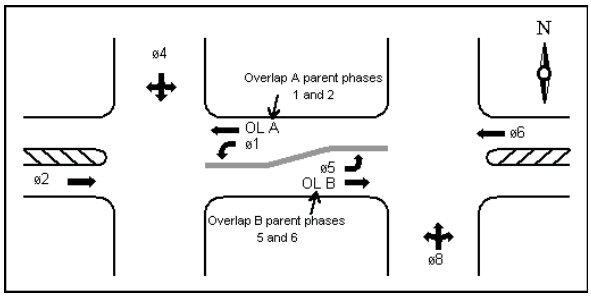
On the **Splits and Phasing diagram** the top number identifies the node number proceed with a # symbol. In the diagram above, the two intersections modeled are intersection #1 and intersection #2.

Clicking on the movement diagram within the Splits and Phasing diagram will jump to the intersection selected. For instance, if the **TIMING** Settings for intersection #1 is active, holding the cursor over any of the movement diagrams for intersection #2 will change the cursor to a hand symbol. Clicking will now change the **TIMING** Settings information to intersection #2.

How to Code an Overlap

An overlap is a green indication that allows traffic movement during the green intervals of and clearance intervals between two or more phases (parent phases). A common application of the use of overlaps is at a diamond interchange using one controller for both ramps. The figure below shows the phase assignments for a typical diamond interchange with overlaps.

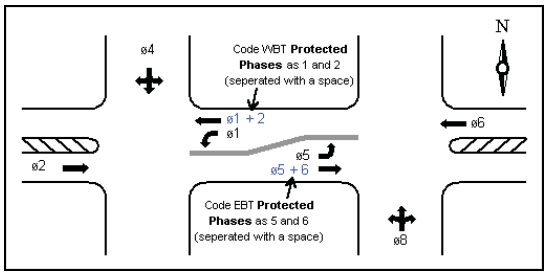
HANDOUT



In this illustration, overlap A operates with its parent phases 1 and 2 and overlap B operates with its parent phases 5 and 6.

To code this with Synchro, you do not need to define a new phase number for overlap A and B in the **Ring and Barrier Designer**. To code this, simply enter 2 and 1, separated with a space, in the **Protected Phases** row for the WBT movement for the left side intersection. Next, enter a 6 and 5, separated with a space, in the **Protected Phases** row for the EBT movement for the right side intersection. See the figure below.

Pay careful attention to **Detector Phases**. They are key to controlling split optimization, as well as skipping and gapping behavior with the actuated green times and in SimTraffic.



The listed phases will become the **Detector Phases.** The phase listed first will be used for split optimization.

Example – Four Phase Sequential Phasing

Open the file **04a 4-phase sequential phasing.syn**. This is an example of how to code the 4-phase scheme shown in the diagram below.

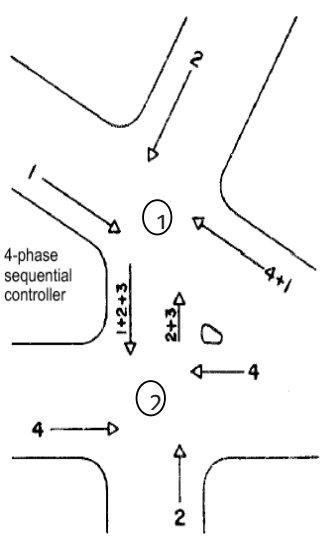
For these types of examples, it is very important to draw a diagram. Once you have labeled your movements, coding the intersection simply becomes a process of entering phase numbers.

In this example, the two intersections will operate under group control. To attach the intersections, use the **Cluster Editor**. Select node #1 and switch to the **TIMING** Settings.

Activate the CLUSTER EDITOR using the command Options→Cluster-Editor.

Click on node #2 to add this intersection to the cluster and select [OK].

Since this is 4-phase sequential, no modifications are necessary to the Ring and Barrier Designer. In the **TIMING**



At node 1
SEL = Perm Phase 1
NBL = Prot Phase 3/Perm Ph 2
SBL = Perm Phase 2

At node 2
EBL = Perm Phase 4
WBL = Perm Phase 4
NBL = Perm Ph 2

HANDOUT

Settings [F5] for intersection 1, begin entering the phase number as shown in the diagram to the right. For instance, the NBL is protected phase 3, permitted phase 2. The SBL is permitted phase 2 and the SBT is protected phase 2.

Refer to the file **04b 4-phase sequential phasing.syn** for the completed example.

Now you can simulate this example by clicking on the ***SimTraffic Animation*** button or press [Ctrl]+[G] to start **SimTraffic**.

Example - Coding a Diamond with Leading Alternating Phasing

In this example, you will code a diamond interchange to operate with Leading-Alternating timing. The Synchro Help file has detailed information on this type of diamond operation. For full details, open the Synchro Help, and search for "Leading Alternating" (use the quote symbols during the search.

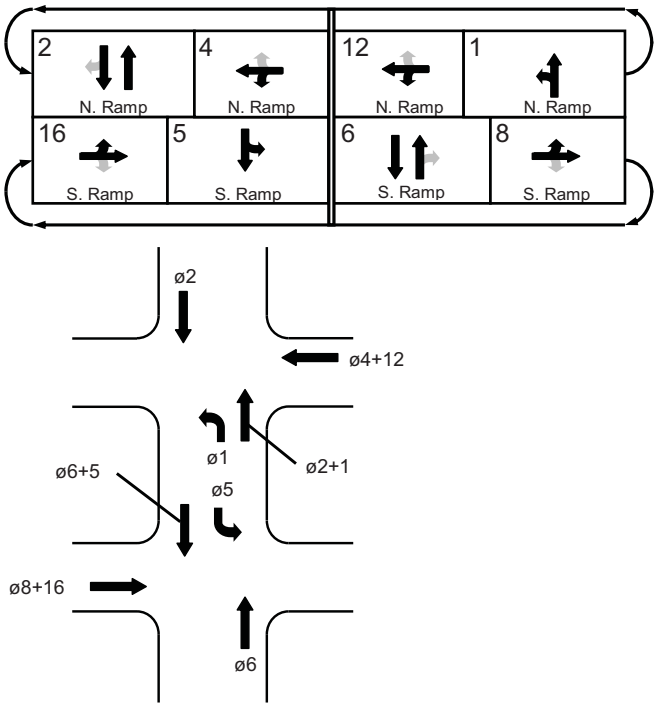
Open the file **05a Diamond for Lead-Alt.syn**. In this example, the network has been created and the lanes and volumes have been entered. It has also been pre-determined that leading-alternating operation will be used.

The two intersections will operate under group control. To attach the intersections, use the **Cluster Editor**. Select node #1 and switch to the **TIMING** Settings.

Activate the **CLUSTER EDITOR** window by using the menu command **Options→ Cluster-Editor**.

Click on node #2 to add this intersection to the cluster and select [OK].

The next step to creating a Leading Alternating Timing plan is to set up the appropriate ring structure in the **Ring and Barrier Designer**. The key is to allow one movement to operate on both sides of the dual ring barrier. The ring structure for this dual ring, Leading Alternating diamond controller is as follows:

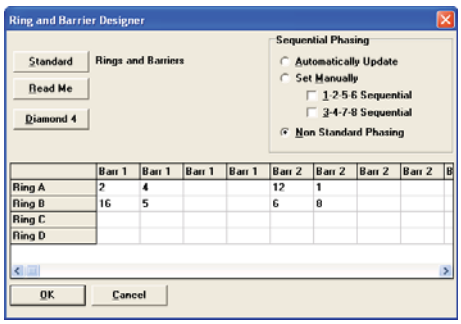


HANDOUT

Notice that the ramp movements are allowed to cross the barrier by reassigning their phase number (4+12, 8+16). For instance, the north ramp westbound movement is allowed to operate within the right barrier as phase 4. It is then allowed to cross into the left side barrier and continue to operate as phase 12.

To set up this structure, switch to the **TIMING** Settings and activate the **Ring and Barrier Designer**. Within the **Ring and Barrier Designer**, select the button **[Diamond 4]**.

The **Ring and Barrier Designer** will automatically appear as shown below:



Select [OK].

At node 1, change the westbound ramp to phase 4+12. Set the NBL to protected Phase 1. The NBT is assigned phase 2 + 1. The SB movements are assigned phase 2.

At node 2, set the eastbound ramp to phase 8+16. The NB movements are assigned phase 6. The SBL is assigned phase 5 (protected) and the SBT becomes phase 6+5.

In the **PHASING** settings, insure that no **Pedestrian Phase** is set for phase 12 and 16 and set the **Minimum Split** and the **Maximum Split** as the travel time between the intersections. For this example, use 6 seconds. Set the **Recall** for phases 1, 5, 12 and 16 to Minimum.

The next step is to find the best timing plan for this interchange. Use the **Optimize→Intersection-Cycle-Length** command to set the intersection to the Natural Cycle Length. The Natural Cycle length is the lowest acceptable cycle length for an intersection operating independently. Synchro will automatically optimize the intersection splits when you perform this step.

For a diamond with leading-Alt, the phase sequence is fixed. Therefore, uncheck (turn off) the Allow Lead/Lag Optimize? for all phases. This will ensure that the phase order does not change during optimization.

Refer to the file **05b Diamond for Lead-Alt.syn** for the completed example.

Now you can simulate this example by clicking on the ***SimTraffic Animation*** button or press [Ctrl]+[G] to start **SimTraffic**.

HANDOUT

4.4 File and Project Management

Merge Files

Use the **File→Merge-File** command to combine or merge two files.

The Merge command can combine some data, such as volumes, one file with other data such as lane geometry and timings from another file.

To Merge files, use the following steps.

1. Open the file to be overlaid. If some intersections exist in both files, start with the file that will be overwritten.
2. Select the **File→Merge-File** command.
3. Select the filename of the second file to merge.
4. The **MERGE OPTIONS** window will appear. Select options and press [OK].

To merge a small file into a bigger file

1. Open the large file first.
2. Select **File→Merge-File** and choose the smaller file. Check all of the merge options on, and merge by ID.

To merge two files from separate areas

1. Open one file first. Use Translate Map command if necessary to adjust coordinates.
2. Select **File→Merge-File** and choose the other file. Check all of the merge options on, and merge by location.

To change coordinates of a file

1. Open the file with correct coordinates first.
2. Select **File→Merge-File** and choose the file with incorrect coordinates. Check all of the merge options on, and merge by ID.

Save Part of a File

The **File→Save-Part** command can be used to split a file into sections or to save part of a file into a separate file.

To use this command:

1. Select one or more intersections to include.
2. Select the **File→Save-Part** command. Choose a filename for the new section. If you choose an existing filename, its data will be overwritten.

Team Management

The Save Part command can be useful for allowing multiple people to work on the same file. Parts of a large network can be saved as separate files. Each team person can work on each piece of the network. The pieces can be combined later using the **File→Merge** command.

HANDOUT

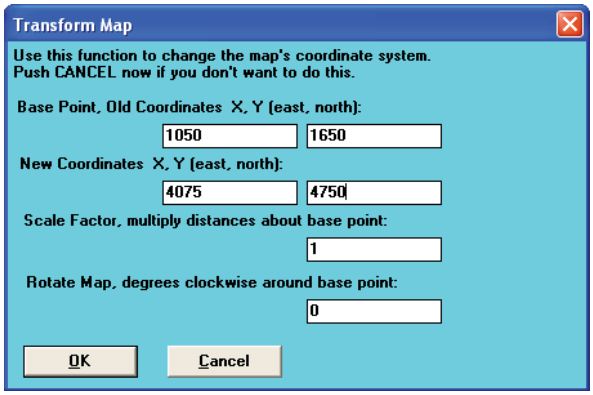
Example - Merging two files together

For this example, refer to the file 'C:\Class Files\Level 2\05b Diamond for Lead-Alt.syn' and 'C:\Class Files\Level 2\01 Prob 1.syn'.

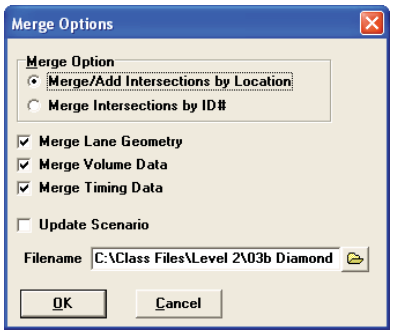
In this example, you can merge two separate files into one larger file. The actual field distance between the South Ramp and G Avenue along C Street is 1500'. In the Diamond file, the southern external link (link 3-2) has already been changed to 500' (using the Intersection Properties to move the node coordinate). In the Prob 1 file, the northern external link (link 7-72) has been changed to 1000'. The coordinate of node 3 (diamond file) and the coordinate of node 72 (Prob 1 file) do not match. When merged, we want these two nodes to connect.

If you attempt to merge files prior to adjusting the world coordinates, the location of the nodes will not be in the appropriate location.

Open the Diamond file. Use the Transform Map button and change the coordinate system around node 3 as shown in the Transform Map View below.



Save the Diamond file and open the Prob 1 file. Use the command **File→Merge** and merge the Diamond file into the Prob 1 file. Be sure to use the 'By Location' option for this merge since you are merging two separate files together.



Try merging the file '01 Prob 1.syn' and '05b SPUI.syn'. This will allow you to see how the SPUI option works compared to the diamond option.

Delete the node that connects to two networks together. The combined files has been Saved-As, **06 Prob 2**.syn and can be found in your Level 2 directory.

HANDOUT

Merging files can be a great time saving feature. For instance, assume you have created 5 files all based on the same basic lane data. Now, assume you want to change the lanes to be equal in all five files (maybe due to data entry errors, or proposed improvements).

Open one of the files (File 1) and edit the Lane data then Save the file. Next, open File 2 and Merge in the Lane data (by ID) from the updated File 1. Do the same for File 3, 4, 5, etc.

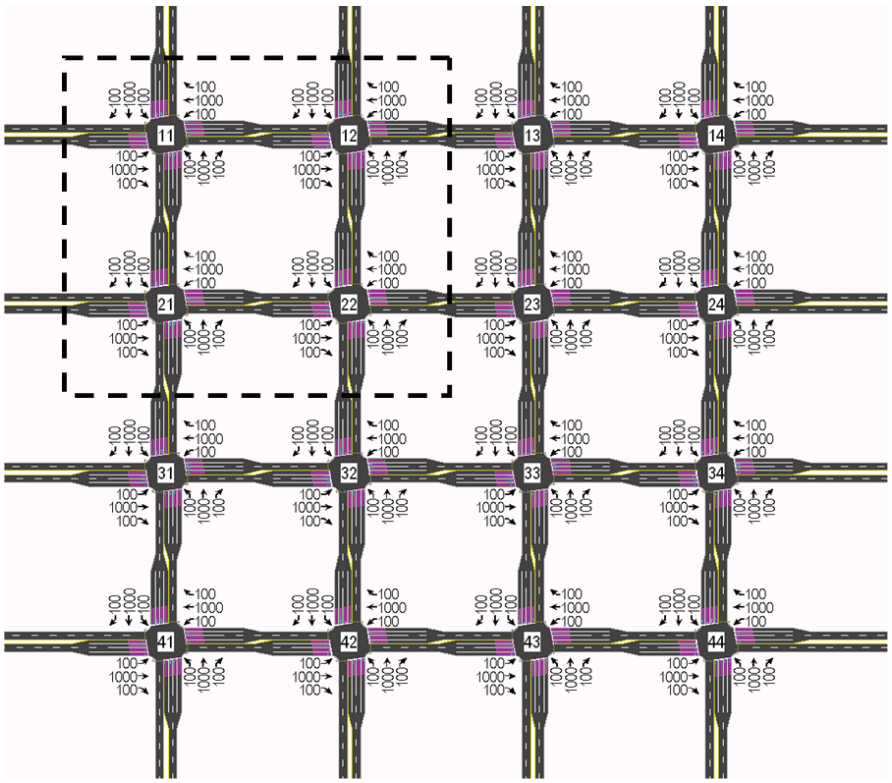
Saving Part of a larger network and merging back into the larger network

For this example, refer to the file '**C:\Class Files\Level 2\07 Grid Network.syn**'.

This is an example of how you can use the file management features to save a smaller portion of a larger file, modify the data in the smaller file and then merge this new data back into the larger file.

To do this, first use the **Save-Part** command to save the four intersections in the northwest corner (nodes 11, 12, 21, and 22). Synchro will suggest a name (filename-P01.syn). You can use this name for the saved part, or choose your own.

After performing the Save-Part, open this smaller file and change some of the data (Lanes, Volumes and Timings). Save the file again and return to the larger file. Now, use the Merge command, however use the 'By ID' feature. Synchro will now merge in the new data from the smaller file for matching node numbers. It is important that you do not change the node numbers in the smaller file prior to this merge.



HANDOUT

4.5 Optimizations

Intersection Split Optimization

Optimizing Splits by Percentile

When optimizing splits, Synchro first attempts to provide enough green time to serve the 90th percentile volumes. If there is not enough cycle time to meet this objective, Synchro attempts to serve the 70th percentile traffic and then the 50th percentile traffic. Any extra time is given to the main street phases.

By attempting to optimize for the 90th percentile, Synchro gives splits that will clear the queue 90% of all cycles. Low volume approaches have more variability in traffic than high volume approaches, and will tend to give lower v/c ratios.

Other rules

If **two or more lane groups** move concurrently, the maximum volume to saturation flow rate is used to set the split.

If two rings are used, the maximum sum of ratios is used for this barrier.

All phases are assigned a split greater than or equal to their Minimum Split.

If there are **permitted left turns,** the entire process above is done repeatedly.

If a lane group is served by two or more phases, its volume will be divided among the phases serving it.

If there is a **shared turning lane plus an exclusive turning lane**, the calculations are repeated even further.

At low volume intersections, there may be extra time available even after accommodating the 90th percentile traffic. In these cases, extra time is given to the coordinated phases for coordinated intersections and is divided evenly among phases at uncoordinated intersections.

Intersection Cycle Length Optimization

Synchro will test all possible cycle lengths for this intersection to determine the shortest cycle length that clears the critical percentile traffic for each phase.

The table below shows what the acceptable Critical Percentile Traffic for each range of cycle lengths.

Cycle Length	Critical Percentile Traffic
40 - 60	90th
61 - 90	70th
91+	50th ($v/c \geq 1$)

Over-Capacity Cycle Length Optimization

The cycle length optimization will choose the cycle length with the lowest performance index. The PI is calculated as follows.

PI = [D * 1 + St * 10] / 3600

$$\text{PI} = \text{Performance Index}$$
$$\text{D} = \text{Percentile Signal Delay (s)}$$
$$\text{St} = \text{Vehicle Stops (vph)}$$

The Percentile Signal Delay adds 450 seconds of delay for each unserved vehicle.

Shorter cycle lengths may also have other operational benefits. Queue lengths are generally shorter and storage bays can operate more efficiently.

HANDOUT

Network Cycle Length Optimization

Performance Index

The best cycle length is found by calculating a performance index.

The PI is calculated as follows.

PI = [D * 1 + St * 10] / 3600

$$\text{PI} = \text{Performance Index}$$
$$\text{D} = \text{Percentile Signal Delay (s)}$$
$$\text{St} = \text{Vehicle Stops (vph)}$$

The percentile delay and the PI count an unserved vehicle as contributing 450 seconds of delay. This causes the cycle length to stop increasing once adding capacity for 1 vehicle will increase delay to other vehicles by 450 s or 7.5 minutes. In general, shorter cycle lengths have shorter uniform delay and will be favored when comparing delays of various cycle lengths.

Network Offset Optimization

Cluster vs. Individual Optimization

During passes 1, 3, and 5; Synchro performs **individual** intersection offset optimization. With individual optimization, the intersection's offset is set to a representative sample of every possible value between 0 and the cycle length -1. With each offset traffic flow bands, the actuated green times, and the delays are recalculated. The offset resulting in the lowest delays is selected. The delays for subject intersection and its neighbors are considered. In some cases the timing of the subject intersection can affect delays at an intersection two or more links away.

During passes 2 and 4, Synchro performs **cluster** optimization. With cluster optimization, Synchro finds groups of intersections that are connected and treats them as a single group. Synchro will adjust the offsets of the entire group together.

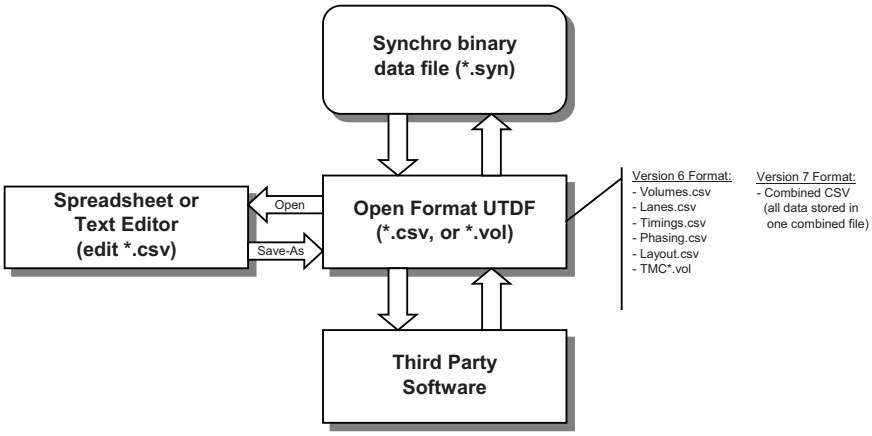
Consider an arterial of 4 intersections. With cluster optimization, the left two intersections will have their offsets adjusted together while the right two intersections are held constant. Whenever a group of two or more intersections are connected to the remainder of the network via a single link, they will be treated as a **dangling** cluster. **Dangling** cluster optimization works well with linear arterial(s).

Another type of cluster is a **CF** cluster. If two or more intersections have Coordinatability Factors between them of 90 (or 70) or more, they are considered a cluster and have their offsets optimized together. CF Cluster optimization helps with situations when two or more intersections are very close have a lot of traffic between them. Without CF cluster optimization, these intersections would tend to be optimized for the benefit of each other only and not for the surrounding intersections.

HANDOUT

4.6 Database Access and UTDF

Universal Traffic Data Format (UTDF) is a standard specification for transferring data between various software packages. UTDF can also be used to share data between software and traffic signal controller hardware. UTDF is also useful for storing multiple volume counts and multiple timing plans for the same intersection.



UTDF uses text files to store and share data. Both comma delimited (*.csv) and column aligned (*.dat) text files are supported. The graphic to the right shows the typical flow of data using UTDF.

Version 6 has six separate UTDF file types and formats. For this course, the volume.csv, tmc#.vol and timing.csv formats will be discussed.

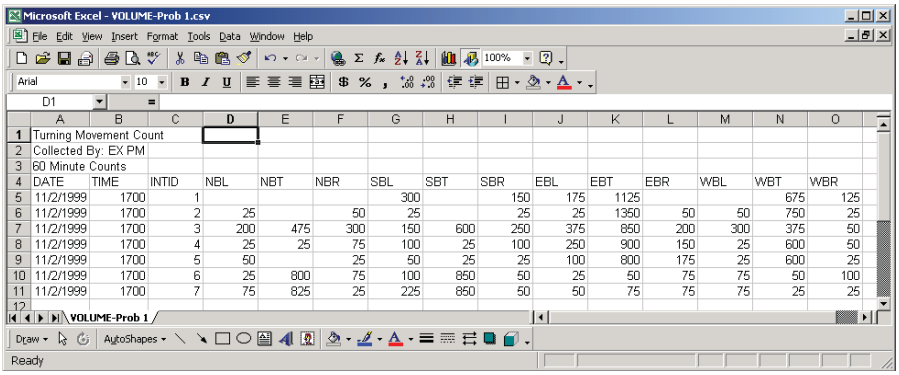
The Volume.csv is useful for working with spreadsheets.

The TMC#.vol format can be used to transfer data from Petra software to UTDF to Synchro.

The Timing.csv and Volume.csv formats are created to allow SimTraffic simulations of multiple timing and volumes in one simulation run (see page 4-31).

Version 6 Volume Data Files

There are several formats for the volume data files. The following is an example of the Problem 1 file Volume database file.



Microsoft Excel - VOLUME-Prob 1.csv

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Turning Movement Count														
2	Collected By: EX PM														
3	60 Minute Counts														
4	DATE	TIME	INTID	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
5	11/2/1999	1700	1				300		150	175	1125			675	125
6	11/2/1999	1700	2	25		50	25		25	25	1350	50	50	750	25
7	11/2/1999	1700	3	200	475	300	150	600	250	375	850	200	300	375	50
8	11/2/1999	1700	4	25	25	75	100	25	100	250	900	150	25	600	50
9	11/2/1999	1700	5	50		25	50	25	25	100	800	175	25	600	25
10	11/2/1999	1700	6	25	800	75	100	850	50	25	50	75	75	50	100
11	11/2/1999	1700	7	75	825	25	225	850	50	50	75	75	75	25	25

This data can be easily modified and saved within a spreadsheet. The advantage to opening this with a spreadsheet is that it will allow the user to edit the data with formulas. For instance, another worksheet tab could be inserted that was a calculation based on the first worksheet.

In version 6 format, you can write multiple Synchro files to a common UTDF file. When you write Synchro data to an existing file, it is added to the bottom of the UTDF file. The existing data is not overridden.

Using Excel to Create UTDF Volume File

Open the file **C:\Class Files\ Level 2\UTDF Files\Sample Volume Adjustments for UTDF.xls**. This spreadsheet is an example impact study. It has been simplified to include only 1 peak period (PM). The worksheets (tabs) are linked together, with the final sheet being a tab that can be saved to Volume.csv format. This can then be imported into Synchro for analysis.

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The header information is important. If the header shows '60 Minute Counts', then ensure that the volumes you have entered are hourly counts. The other format accepted is '15 Minute Counts'.

If the counts are hourly counts, then you will not be able to have Synchro calculate the PHF.

Be sure to set the 'Scope' to the appropriate setting when you are reading and writing data.

You can attempt to modify any of the sheets, although this has already been set-up. Notice that some changes are linked to other sheets, including the final worksheet which is the UTDF format.

Click on the last sheet in the spreadsheet. Save the spreadsheet first. Next, use the Excel Save-As command and save this one sheet as a CSV format.

Open the file **06 Prob 2**.syn. Import the 2010 Opening Day volumes into this file. Save the file with a new name. The file that has imported volumes in it is called **08 Prob 2 w 2010 Open Day.syn**. This file has NOT been optimized. Attempt to optimize the system.

Reading Volume Data

The Volume file(s) stores turning movement counts. The volume file(s) stores the intersection number along with the date, and time of the volume data.

To read Volume data from the Volume file do the following:

1. Activate the **DATABASE ACCESS** window, press [Ctrl] + [D].
2. Select the **[Read Volumes]** tab.
3. Select the **File Style**.
4. Press **[Select]** to select the file or directory for the data file(s).
5. If desired, select a time or range of times. If the times are blank, all times will be read.
6. Select a day of the week to limit dates by.
7. Select an intersection, a zone, or entire network.
8. Choose an Averaging Method.
9. Choose **Set PHF** if your data is in 15 minute intervals and you want to automatically calculate PHFs.
10. Choose [Read].

The Volume data from this Synchro file will now be in the Volume file.

Writing Volume Data

The VOLUME file(s) stores turning movement counts. The volume file stores the intersection number along with the date, time, and source of the volume data.

To write Volume data to the Volume file do the following:

1. Activate the **DATABASE ACCESS** window, press [Ctrl]+[D].
2. Select the **[Write Volumes]** tab.
3. Select the **File Style**.
4. Press the **[Select]** to select the file or directory for the data file(s).
5. Enter the date and time for this volume data. Times are entered in military format as hhmm.
6. Enter a comment for this data. A comment can indicate who or what collected the data.
7. Select an intersection, a zone, or entire network.
8. Choose **[Write]**.

The Volume data from this Synchro file will now be in the Volume file.

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Using UTDF to read TMC style counts

For this example, use the Synchro file '**C:\Class Files\Level 2\09a 120th Street.syn**'. The TMC files are in the directory '**C:\Class Files\Level 2\TMC**'.

This is an example of how to use the UTDF Read volume feature to read a 15-minute volume count. The files are turning movement count (TMC) files that were created with the PETRA software.

Open your turning movement count file with Petra (*.pwf file). Use the command **File→Export**, choose the Save as Type 'AAP (*.vol)'. For the filename, enter a number only. This number MUST match the node number of the intersection in Synchro. Select the [Save] button and you'll see an AAP Export Dialog. Select the banks with data and press [OK]. The TMC file will be stored in your directory with the format TMC#.vol.

Open one of the TMC files and observe the format. It is important that the heading states '15 Minute Turning Movement Count' and that the Reference # matches the Node ID number in Synchro. In addition, the Filename must be TMC#.vol where the # must be the same as the node number. For the image shown below, this is the TMC for node 10.

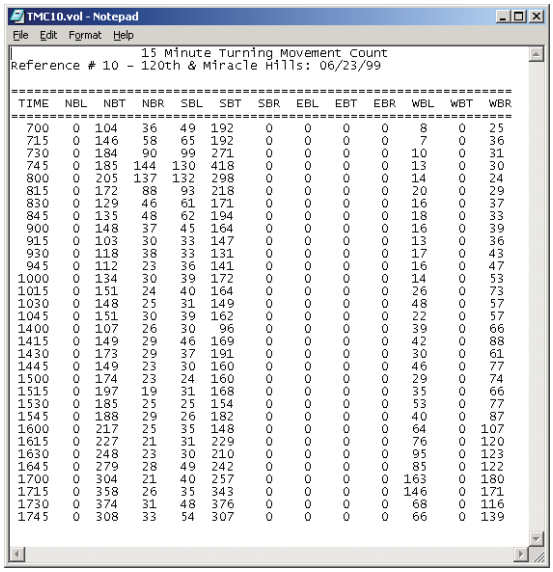
Try the following example:

1. Open your Synchro File (**09a 120th Street.syn**)
2. Select Database Access, press [Ctrl] + D
3. Select the "Read Volume" tab.
4. For file style, use the "By Int, TMC Style (TMC###.VOL)"
5. Choose [Select] and locate the directory with the TMC#.vol file.
6. For times, select the appropriate range and select the "Set PHF" check box if you want Synchro to calculate the PHF. To find the A.M. peak, set the range from 700 to 900, or whatever time period you are interested in.
7. Press the "Read" button. Now, import this data into the Synchro file. Try different time periods and averaging methods.

This process discusses how counts from a **JAMAR** count board, and **PETRA** software can be converted to a format that can be read by Synchro.

The Maximum Peak hour will be determined By Intersection. Therefore, if you set your queuy across multiple times, the peak hour could differ at intersections.

If you are looking for a system peak, you would need to determine this time off-line. Then, you could set your import limits to only include this system peak hour.



TMC10.vol - Notepad

File Edit Format Help

15 Minute Turning Movement Count
Reference # 10 - 120th & Miracle Hills: 06/23/99

TIME	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
700	0	104	36	49	192	0	0	0	0	8	0	25
715	0	146	58	65	192	0	0	0	0	7	0	36
730	0	184	90	99	271	0	0	0	0	10	0	31
745	0	185	144	130	418	0	0	0	0	13	0	30
800	0	205	137	132	298	0	0	0	0	14	0	24
815	0	172	88	93	218	0	0	0	0	20	0	29
830	0	129	46	61	171	0	0	0	0	16	0	37
845	0	135	48	62	194	0	0	0	0	18	0	33
900	0	148	37	45	164	0	0	0	0	16	0	39
915	0	103	30	33	147	0	0	0	0	13	0	36
930	0	118	38	33	131	0	0	0	0	17	0	43
945	0	112	23	36	141	0	0	0	0	16	0	47
1000	0	134	30	39	172	0	0	0	0	14	0	53
1015	0	151	24	40	164	0	0	0	0	26	0	73
1030	0	148	25	31	149	0	0	0	0	48	0	57
1045	0	151	30	39	162	0	0	0	0	22	0	57
1400	0	107	26	30	96	0	0	0	0	39	0	66
1415	0	149	29	46	169	0	0	0	0	42	0	88
1430	0	173	29	37	191	0	0	0	0	30	0	61
1445	0	149	23	30	160	0	0	0	0	46	0	77
1500	0	174	23	24	160	0	0	0	0	29	0	74
1515	0	197	19	31	168	0	0	0	0	35	0	66
1530	0	185	25	25	154	0	0	0	0	53	0	77
1545	0	188	29	26	182	0	0	0	0	40	0	87
1600	0	217	25	35	148	0	0	0	0	64	0	107
1615	0	227	21	31	229	0	0	0	0	76	0	120
1630	0	248	23	30	210	0	0	0	0	95	0	123
1645	0	279	28	49	242	0	0	0	0	85	0	122
1700	0	304	21	40	257	0	0	0	0	163	0	180
1715	0	358	26	35	343	0	0	0	0	146	0	171
1730	0	374	31	48	376	0	0	0	0	68	0	116
1745	0	308	33	54	307	0	0	0	0	66	0	139

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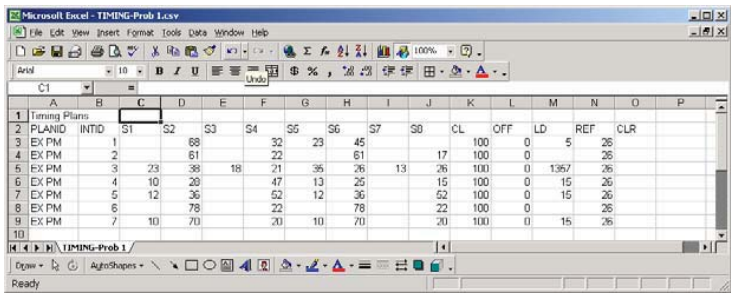
To add timing data to an existing UTDF file, simply write the new data to an existing timing file. The new data will be added to the bottom of the Timing file.

The filename does not have to be named Timing.csv. Use any filename that is logical to you.

Timing Data

The TIMING file stores information about the timing plans including splits, cycle lengths, and offsets. This data can vary by time of day and thus multiple Timing records for each intersection are allowed.



Timing Plans															
PLANID	INTID	S1	S2	S3	S4	S5	S6	S7	S8	CL	OFF	LD	REF	CLR	
EX PM	1		68		32	23	45			100	0	5	26		
EX PM	2		61		22		61		17	100	0		26		
EX PM	3	23	38	18	21	35	26	13	26	100	0	1357	26		
EX PM	4	10	20		47	13	25		15	100	0	15	26		
EX PM	5	12	36		52	12	36		52	100	0	15	26		
EX PM	6		78		22		78		22	100	0		26		
EX PM	7	10	70		20	10	70		20	100	0	15	26		

To write Timing data to the Timing file do the following:

1. Activate the **DATABASE ACCESS**, press [Ctrl]+[D].
2. Select the **[Timings]** tab.
3. **[Select]** a filename for the timings file. Use the extension .CSV for comma delimited.
4. Enter a name for the timing plan with up to 8 characters. Examples of a plan could be AMPEAK or MIDDAY.
5. Select an intersection, a zone, or entire network.
6. Choose **[Write]**.

The Timing data from this Synchro file will now be in the Timing file.

To read Timing data from the Timing file into Synchro, do the following:

1. Backup your Synchro data file.
2. Activate the **DATABASE ACCESS**, press [Ctrl]+[D].
3. Select the **[Timings]** tab.
4. Choose a timing plan from the list of existing names.
5. Select an intersection, a zone, or entire network.
6. Choose **[Read]**.

UTDF 2006 (Version 7)

The version 7 UTDF has been reformatted to contain all the data in one combined file. The data is divided by sections in the comma delimited (CSV) format. The UTDF Combined file can be accessed through the **File→Open**, **File→Save-As**, **File→Merge** and **File→Save-Part** commands.

The new combined file format contains multiple sections so that a single file can completely define a network. The combined format includes the data previously found in the LAYOUT, LANES, and PHASING files. These individual file formats will be phased out in the future. The combined file includes sections for Network, Nodes, Links, and Timing Plan allowing a better mapping of data.

The single combined file and its respective sections now include all data available in Synchro. Refer to Chapter 16 of the **Synchro Studio 7 User Guide** for full details

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Reading and Writing UTDF Data

Data for UTDF 2006 is stored in one combined file. Data is separated into sections as detailed in the Synchro Studio User Guide. Often, users want a sample UTDF compatible format. The best way to see this is to open an existing Synchro file and create (write) the data to UTDF.

To **write** out a UTDF file, do the following:

1. Open the Synchro file for which you want to write data out.
2. Select the menu command **File→Save-As**.
3. Choose Comma Delimited from the 'Save as Type' dropdown
4. Enter a 'File name' and press **[Save]**.
5. The data from this Synchro file will now be in CSV file.

If there is data in the CSV file that you do not want to merge, delete from the CSV file prior to merging.

Synchro CSV data can be modified with a text editor or a spreadsheet. See the topic on **Editing UTDF Data with Other Software** below.

To **read** CSV data into an **existing** Synchro file, do the following:

1. Backup your Synchro file.
2. Select the menu command **File→Merge**.
3. Choose a CSV file from the list and press **[Open]**.

The data from the selected CSV file will now be in the Synchro file. This process does not create new links or nodes, and does not move or renumber nodes. It will merge in data from the Data Settings screens for matching node numbers.

To **read** CSV data into a **new** Synchro file, do the following:

1. Select the menu command **File→Open**.
2. Choose Comma Delimited from the 'Files of type' dropdown
3. Choose a CSV file from the list and press **[Open]**.

The data from the selected CSV file will now be in the Synchro file. This process imports all of the CSV data into the Synchro file, including nodes and links.

Editing UTDF Data with Other Software

The UTDF 2006 file is a comma delimited (CSV) file. To edit the CSV files simply open the files with a spreadsheet such as Microsoft® Excel. Be sure to save the file as comma-aligned and not as Excel format. If you have created any formulas in your spreadsheet, be sure to first save the file in spreadsheet format. Then, save the file to UTDF CSV format.

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4.7 Advanced SimTraffic Features

This section covers the advanced features of SimTraffic. For many simulations, these parameters can be left at the defaults.

Intervals and Volume Adjustments

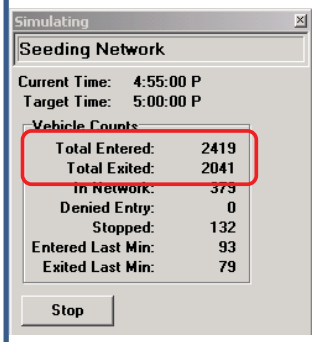
Choose the **Options→Intervals-and-Volumes** command to activate the Intervals page.

Intervals

Each column represents an interval. Normally a simulation has a "seed" interval followed by one or more recorded intervals.

The purpose of the **Seed Interval** is to fill the network with traffic. The **Recorded Interval(s)** follow the seed interval and these intervals are recorded for animation, reports, and static graphics.

It is possible to have a congested peak interval of say 15 minutes, followed by an off-peak interval to see how quickly the network recovers from congestion. Multiple intervals can also be used to simulate multiple timing plans and the transition between timing plans.



Setting the Seed Time

The seeding time should be long enough for a vehicle to traverse the entire network between the two most distant points including all stops. The seeding time should also be longer than the maximum cycle length in the network. After the seeding time, the number of vehicles entering the network per minute should be about the same as the number of vehicles exiting the network per minute. Look at the Vehicle Counts in the Status window during seeding and recording to see how many vehicles are entering and exiting the network.

If one or more movements are above capacity, the number of entering vehicles will always exceed the number of exiting vehicles, and equilibrium will not be achieved. In this case, the seed time should be long enough so that the number of exiting vehicles per minute stabilizes at a fixed value.

Volume Adjustments

The volumes simulated come from the Traffic Volumes in the *.SYN file or from an external data file. These volumes can be adjusted by a number of factors.

Set **Growth Factor Adjust** to adjust for growth factors. The growth factors are input in Synchro's Volume Settings and are 100% by default.

Set **PHF Adjust** to adjust for peak hour factors. Volumes are divided by the PHF.

Set **AntiPHF Adjust** to unadjust for peak hour factors. The PHF increases the hourly count for the peak 15 minute period. The volume for the remaining 45 minutes will thus be decreased from the hourly rate

Set **Percentile Adjust** to create a pulse of traffic based on Poisson arrivals. The percentile adjust can be used to model a 95th percentile queue or to see how a network fares with peaking traffic conditions.

Database Parameters

The last two rows of the Intervals page are used in conjunction with external data files. See Data Access for more information about using data files.

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Timing Plan ID is used to specify a timing plan from a timing data file. The timing data file may contain more than one set of timing plans and the timing plan ID specifies which one to use.

Data Start Time is used to identify which volume counts to load from a volume data file. A volume data file may contain multiple volume counts, each marked with a different set of dates, times, and intersection ID numbers.

Random Number Seed

SimTraffic uses random numbers to determine when new vehicles and pedestrians enter the network and for choosing vehicle paths through the network. The random number seed can be used to generate the same sequence of vehicle entries or to create a new sequence each time.

If random number seed is **zero (0)**, SimTraffic will choose a random number seed at random. All simulations with random number seed 0 should be unique from each other.

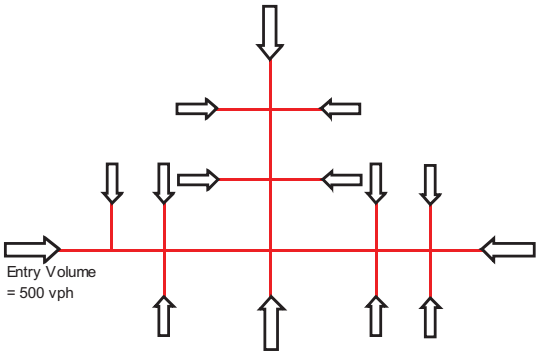
The Federal Highway Administration (FHWA) is currently in the process of creating guidelines regarding the number of simulation runs. This falls under the Next Generations Simulation (NGSIM) project. Current thinking is to suggest that the user simulates each model with 4 or 5 runs with varying random seeds. Check the NGSIM website for details:

www.ops.fhwa.dot.gov/Travel/Traffic_Analysis_Tools/ngsim.htm

Trip Generation

Trips are added to entry links based on the volume counts at the intersection.

Trips are also added mid-block if mid-block traffic is specified or a volume source is needed to balance traffic. If both balancing and a mid-block source exist, the mid-block entry will be the maximum of the two.



For each 0.1 s slice a vehicle is created when R36000 < vl

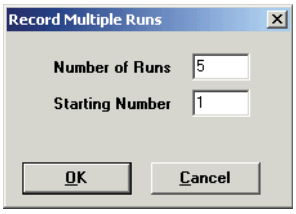
vl = hourly traffic volume of link or mid-block source.

R36000 = a random number between 0 and 35999

For any given time period more or less vehicles will appear. Looking at many time periods, the vehicles will exhibit a Poisson arrival distribution.

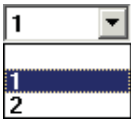
Consider the graphic above with the EB entry volume of 500 vph. Over an hour there are 36000 chances to add vehicles and about 500 of the random numbers will be less than 500 and about 500 vehicles will be created. For example, if random number 498 is selected, a vehicle will be created and placed in the network if it is OK to enter. If it is not, it will be held in denied entry until it is OK to enter. There must be space on the link to allow a vehicle to enter.

Link Volumes are calculated independently for cars and for heavy vehicles. The heavy vehicle volume is equal to the adjusted volume times the Heavy Vehicle percentage. The car volume is equal to the remaining adjusted volume. Entering Heavy Vehicles are assigned to a Truck or Bus vehicle type based on their percentage of the total Heavy Vehicle Fleet. Entering Cars are assigned to a Car or Carpool vehicle type based on each type's percentage of the total Car Fleet.



Multiple Simulation Runs

The ***Record-Multiple Runs*** button or [Ctrl]+[M] will perform and record a simulation on multiple runs. A dialog will appear allowing the user to select the number of runs to simulate and record and the starting random number seed. The random number seed will be incrementally increased by one for the simulated runs. For instance, 1, 2, 3, 4 and 5 if starting from 1 with 5 runs.



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The Run Number of Recorded History will allow the user to load a recorded history file if multiple runs have been performed. Choose the number of the run you would like to animate with the drop down list. The number will be the random seed number that was used. It is possible to have a blank value in the drop-down list. This indicates a simulation run without a run number extension.

In the reports, the user is allowed to have the report generator average the results for some of all of the runs performed.

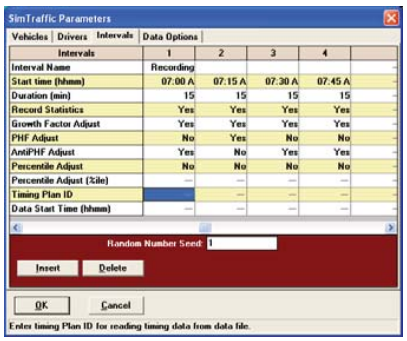
Only the separate values for each run can be shown for the Performance Reports. Queues, Actuated Timings and Simulation Summary will be the average of the runs only.

Creating a Multi-Simulation Report

SimTraffic will generate a report that averages the results of multiple runs. Check the 'Multiple Runs' box prior to selecting the [Print], [Preview], or [Save-Text] buttons. A dialog box will appear showing the History (HST) files for each simulation run recorded. The format of the history file will be 'filename-#.hst' where # indicates the random seed number. Select the runs you want to average by holding the [Ctrl] key and clicking on the desired filenames. The resulting report will be the **average** of the files you have selected. To see the results for the individual history files, create a report that selects only the desired history file.

Using the Peak Hour Factor Adjustment in SimTraffic

In SimTraffic, there are several methods to account for the peaking conditions, or peak hour factor (PHF) within an hour simulation. One method would be to simulate 4 intervals of 15 minutes using the UTDF feature (see the topic, DATABASE ACCESS in the SimTraffic help file). In this case, SimTraffic reads the 15-minute counts from a database and let the simulation model handle the peaking of the volumes. You can then get reports in SimTraffic for each interval and an aggregate total.



Intervals	1	2	3	4
Interval Name	Recording			
Start time (hhmm)	07:00 A	07:15 A	07:30 A	07:45 A
Duration (min)	15	15	15	15
Record Statistics	Yes	Yes	Yes	Yes
Growth Factor Adjust	Yes	Yes	Yes	Yes
PHF Adjust	No	Yes	No	No
AntiPHF Adjust	Yes	No	Yes	Yes
Percentile Adjust	No	No	No	No
Percentile Adjust (%ile)	—	—	—	—
Timing Plan ID		—	—	—
Data Start Time (hhmm)	—	—	—	—

Another approach would be to use the PHF adjust in SimTraffic. In this case, set one of four intervals with the PHF adjust, and the other three intervals with the anti-PHF adjust.

Consider an example where you have a total of 1000 vph in the system with a PHF of 0.8. If this peak occurs during interval 2 (assumes 4-15 minute intervals simulated), do the following:

1. Int 1: Set **Anti PHF**, Volume simulated = (1000/4)*(1 - (1/PHF- 1)/3))=250*(1-(1/.8-1)/3))=229 veh
2. Int 2: Set **PHF Adjust**, Volume simulated = (1000/4)/0.8=313 veh
3. Int 3: Set **Anti PHF**, Volume simulated = 229
4. Int 4: Set **Anti PHF**, Volume simulated = 229
5. Total Volume for hour = 229*3 + 313 = 1000 vph.

Database Access uses UTDF files. See the section on UTDF beginning on page 4-23. An example of using this feature can be found on page 4-31.

Database Access

The database access feature allows volume counts and timing plans to be read from an external data file. The database feature is useful to model multiple intervals with more than one timing plan or volume count.

The data files are UTDF style comma separated files (CSV).

The Data Options page can be accessed with the Options→Database-Access command.

Volume Data Options

To read volume counts from a data file, check the **Read Volumes** box. This feature is most useful when two or more counts will be simulated in two or more intervals.

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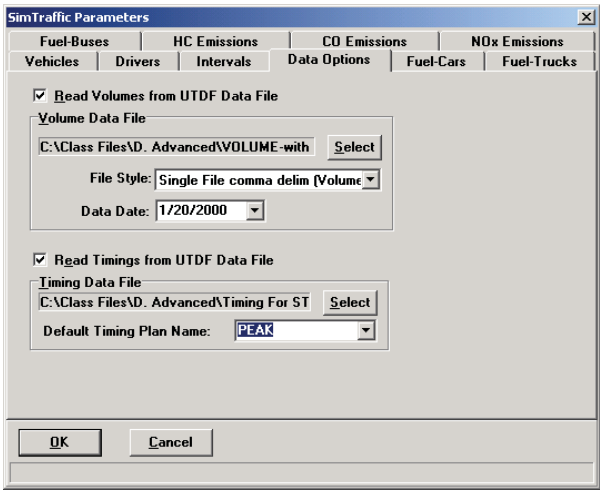
Timing Data Options

To read timing plans from a data file, check the **Read Timings** box. This feature is most useful when two or more timing plans will be simulated in two or more intervals. This feature can be used to model transitions between timing plans.

SimTraffic UTDF Example

For this example, refer to the Synchro file '**C:\Class Files\Level 2\10 Using ST UTDF Feature**.syn'. In addition, you will use the files '**Timing for ST UTDF.csv**' and '**Volume-with ST UTDF.csv**'.



This is an example of how to use the SimTraffic UTDF (database) access feature. Use these files to setup different timing intervals for the two timing plans (in the Timing database file) and for volumes from the volume database file.

To get SimTraffic to read from a database, there still is some set-up required. Once you launch SimTraffic, stop the recording. Then use the command **Options→Database-Access**. Check the 'Read Volumes from UTDF Data File' box and then select where your UTDF database file is. Be sure to choose the appropriate Data Date.

Then, check the 'Read Timings from UTDF Data File' and select where the timing data file is. Select a default timing plan.

Switch to the Intervals tab use the [Insert] button to insert the desired number of intervals. For volumes, select the appropriate Data Start Time for each interval. Also, choose the appropriate Timing Plan ID for the timing plan you want to simulate for each interval.

Vehicle Parameters

The **Vehicle Parameters page** can be accessed with the **Options→Vehicle-Parameters** command.

Vehicle Name is used to identify the vehicle type in the Vehicle Status window.

Vehicle Occurrence defines what percentage of the vehicle fleet is made up of this vehicle type. The default "percentages" are shown below.

Car1	Car2	Truck SU	SemiTrk1	SemiTrk2	Truck DB	Bus	Carpool1	Carpool2
64%	16%	60%	10%	5%	5%	20%	16%	4%

Normally, you do not want to modify the vehicle parameters. These should only be used for unique situations, or if you have access to better data.

The fleet mix will add up to 100% for trucks and 100% for car types.

Maximum Speed is used in conjunction with the **Maximum Acceleration** to determine the acceleration available at a given speed.

Vehicle Length is used to determine the length of each vehicle type.

Vehicle Width is used for the width of the vehicle. This value is used for graphics only and has no affect on the simulation model.

Vehicle Fleet is used to assign a vehicle type to a fleet. The fleet can be car, bus, truck, or car pool.

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Vehicle Occupancy is the number of people per vehicle. SimTraffic does not currently use this value.

The **Default** button will reload the default parameters for all the vehicles.

When vehicles are created, they are randomly assigned a driver type between 1 and 10. Each driver type represents 10% of the driving population with driver type 1 being the most conservative and driver type 10 being the most aggressive.

These percentages cannot be changed. If you wanted more aggressive drivers, you could modify the parameters for the more conservative driver types.

Driver Parameters

The **Driver Parameters page** can be accessed with the **Options→Driver-Parameters** command.

Yellow Decel is the maximum deceleration rate a driver is willing to use when faced with a yellow light.

The **Speed Factor** is multiplied by the link speed to determine the maximum speed for this driver.

Courtesy Decel Rate (CDR) is the amount of deceleration a vehicle will accept in order to let allow an ahead vehicle in an adjacent lane to make a mandatory lane change.

Yellow React is the amount of time it takes the driver to respond to a signal changing to yellow.

Green React is the amount of time it takes the driver to respond to a signal changing to green.

Headways are the amount of time between vehicles drivers try to maintain. Normally, you would not want to modify this setting. You could modify the Headway Factor (see page 2-32) for individual links.

Gap Acceptance Factor is an adjustment to the approach gap times. This is the gap vehicles will accept at unsignalized intersections, for permitted left turns, and for right turns on red.

The range of values for Positioning and Optional Advantage is 0.5 to 20 vehicles. If all vehicles ahead are moving, they count as a fraction of a vehicle depending on the speed of the slowest vehicle ahead.

A driver will defer making a Positioning Lane change when there is **Positioning Advantage** more vehicles ahead in the target lane than the current lane. Higher Values are associated with more conservative drivers and cause drivers to line up in the correct lane. Lower Values are associated with aggressive drivers and cause drivers to avoid lining up in the correct lane until reaching the mandatory lane change point.

A driver will make a Desired Lane change when there is **Optional Advantage** less vehicles ahead in the target lane than the current lane. Higher Values are associated with more conservative drivers and cause drivers to have unbalanced lane use. Lower Values are associated with aggressive drivers and cause drivers to use lanes evenly.

Mandatory Lane Change Distance Factor (MLCD) is the factor the mandatory lane change distances are multiplied by. The default values are:

Driver Type	1	2	3	4	5	6	7	8	9	10
MLCD Factor (%)	200	170	150	135	110	90	80	70	60	50

The **Positioning Distance Adjustment Factor** (PDA) is used to multiple the Positioning Distance value for each driver type. The default values are:

Driver Type	1	2	3	4	5	6	7	8	9	10
PDA Factor (%)	150	140	130	120	110	95	90	80	70	60

The Mandatory Distance values and Positioning Distance values are shown in the Synchro **Simulation Settings** screen. The values (as illustrated below) are the values used for each

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driver type (DT) multiplied by the factors illustrated in the tables above. For instance, a DT 1 Mandatory Distance for a single lane change is 750' x 200% = 1500'. The Mandatory Distance for a DT 10 is 750' x 50% = 375'.

The Positioning and Mandatory values are used to control how vehicles will make lane changes. Increasing these values will force vehicles to make lane changes sooner. Increased values would therefore cause queues to be longer if vehicles need to position for downstream lane changes.

Normally, it is best to edit the Lane Change Distances by link in the Synchro. If you change the Driver Parameters page in SimTraffic, the change will be universal to the entire network.

Mandatory Distance (ft)	—	750	—
Positioning Distance (ft)	—	1761	—
Mandatory Distance 2 (ft)	—	1174	—
Positioning Distance 2 (ft)	—	2348	—

Create SSAM Export

In SimTraffic, there is a new **Animate→ Create SSAM Export**. If this option is checked, SimTraffic creates a *.trj file during the simulation recording. This file describes the position of the vehicles throughout the simulation. It is a binary file compatible with FHWA's Surrogate Safety Assessment Model (SSAM). SSAM can be used to analyze the frequency of narrowly averted vehicle-to-vehicle collisions.

There are several points that may be discussed and adjusted:

1. Vehicle speed is in km/h or mph depending if the system is metric or not.
2. Time period is 0.5 sec

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7 MODEL CALIBRATION

Today, traffic engineers and other practitioners are generally in agreement that a properly timed traffic signal system will reduce travel time, delays, vehicle stops, and fuel consumption. Numerous research studies and successful timing projects in cities across the United States in the last twenty years have supported this theory. Based on "before-and-after" studies, many of these studies have reported reductions in travel time, stops, delays and fuel consumption in the range of 10 percent to 40 percent and benefit-to-cost ratios as high as 100-to-1. In recent years, air quality improvements have been added to the list of benefits.

The benefits of improved signal timing are especially desirable for several reasons. First, the benefits are realized directly by the motoring public (and their passengers) who use the transportation system. Second, there is no discrimination regarding the distribution of these benefits; all consumers reap the rewards of reduced traffic congestion, reduced fuel consumption, operating cost savings, and improved air quality. And finally, these benefits continue to be realized year-after-year.

However, to truly realize the benefits of a properly timed signal system, it is critical to evaluate the results of the signal timing project that was performed.

7.1 Computer Model Measures of Effectiveness

Computer modeling is one of the more important tools in traffic engineering. If a traffic system is modeled on a computer, it is possible to predict the effect of multiple traffic timing plans on the system's operational performance, as expressed in terms of measures of effectiveness (MOEs), which include average vehicle speed, vehicle stops, delays, vehicle-hours of travel, vehicle-miles of travel, fuel consumption, and pollutant emissions. The MOEs provide insight into the effects of the signal timing project, and they also provide the basis for optimizing that strategy.

Computer modeling has the following advantages over a field experiment:

- ✓ It is less costly.
- ✓ Results are obtained quickly.
- ✓ The data generated by computer modeling include several measures of effectiveness that cannot be easily obtained from field studies.
- ✓ The disruption of traffic operations, which often accompanies a field experiment, is completely avoided.
- ✓ Many schemes require significant physical changes to the facility, which are not acceptable for experimental purposes.
- ✓ Evaluation of the operational impact of future traffic demand must be conducted by using simulation or an equivalent analytical tool.
- ✓ Many variables can be held constant.

The availability of traffic modeling and optimization programs greatly expands the opportunity for the development of new traffic signal timing plans. Since the results generated by the model can form the basis for selecting the most effective candidate among different timing plans, the eventual field implementation will have a high probability of success.

In Chapter 6, there was an introduction to Synchro 6 reporting. The following sections will highlight in more detail some of the computer model results that can be obtained from the Synchro 6 program.

7.2 Computer Model Calibration

Calibration is the process of adjusting input data and model parameters in order to ensure that the simulation results from the models match observed traffic performance in the field. Calibration is an important step in a signal timing project because the development of optimal timing plans depends on how closely the model represents the existing conditions. Calibration should be based on the knowledge of the existing conditions in the network and correct interpretation of the model outputs.

Calibration really serves two purposes:

- ✓ It is a "final" check on the quality of the general input data, and
- ✓ It involves the "fine-tuning" of the traffic parameters to ensure that their modeling are realistic.

The following general steps should be taken, at a minimum, once all base data have been coded in the model and initial runs have been made to clear up obvious coding problems:

- ✓ Before continuing any further, double check the base input data.
- ✓ Compare the following measures of effectiveness (MOE's) to ensure that the values are consistent with the way you know the system operates:
- ✓ Degrees of saturation
- ✓ Delay and average travel times; and
- ✓ Maximum queue length, or maximum back of queue, depending on the model.
- ✓ If you are not certain of the actual system operation, or if any of the above MOEs do not "measure up" as expected, conduct field studies to verify field conditions.
- ✓ For the more sophisticated models, conduct field studies for the significant advanced modeling features (i.e., such as the linked flow movements within CORSIM).
- ✓ Vary the appropriate model parameters to bring the simulated or estimated results into better agreement with the field data.
- ✓ Always, continually look for overlooked data errors.

This process demands a thorough understanding of the results and outputs of the various models. Recall that the same MOE may be calculated differently by several programs, and may not even include the same basis of measure.

Data Verification

Verifying the accuracy of input data is both an important and continuous task. It is so critical to do this early in the process, because if a significant error is not discovered until, for example, the design process has been completed, a considerable amount of work and computer runs may have to be repeated. Nonetheless, do not conclude that all data are correct after this final check. You must be continuously on the alert for data errors throughout the calibration, design and evaluation stages.

The process at this step is relatively simple. Have a person who has not been intimately involved in the coding process carefully review all input data to insure that they agree with the original sources. The key data item to check should include as a minimum:

- ✓ Traffic volumes, particularly if a data preprocessor was used to develop more detailed relationships.
- ✓ Capacity parameters (saturation flow rates and lost times) if these were based on field studies. If they are estimated, make sure that the values are reasonable for the conditions.
- ✓ Speeds and other related data.
- ✓ Signal timing.

Degree of Saturation

As described in Chapter 4, the degree of saturation is defined as:

$Y = vC / sg \times 100$ (%)

where,

Y = degree of saturation expressed here expressed as a percentage;

v = volume in vph,

C = cycle length in seconds,

s = adjusted saturation flow in vphg, and

g = effective green (split time - lost time).

$g = G - SLT + EEG$, or

$g = G + Y + R - L$

and, G = actual green time,

SLT = start-up lost time,

EEG = extension of effective green,

Y,R = yellow and all-red time, and

L = total lost time.

The degree of saturation, also the volume-to-capacity ratio (v/c), is an indicator of the level of congestion on the particular link. At high degrees of saturation, traffic on the link experiences substantial delays and frequent cycle failures. You should compare the degree of saturation for each link with what you know to be the existing conditions in the field. Significant differences between the predicted and actual intersection operations indicate that the input data may need adjustments. For example, if critical intersections are indicated as saturated in the program (X is approaching or exceeding 100%) and, if so, check whether this is not actually occurring.

Timing and Lost Time

If re-examining the volumes does not clear up the problem, check the timing and lost time. Of course, the cycle length should have been coded correctly, so the likely culprit is the phase length and/or lost time.

For pre-timed controllers, the timing is trivial to check, but this may also indicate the need for a field check of a particular controller.

Actuated control is a different story. Theoretically, minor (actuated) movements should be operating near saturation. If the models say they are not, the estimates of the green times are likely not correct (unless of course all phases are operating on recall, thus destroying the purpose of actuated control).

As with timing data, lost time can be a source of highly sensitive fluctuations in the intersection measures of effectiveness.

Maximum Queue Length or Back of Queue

Compare the predicted maximum queue length (MQL), or maximum back of queue (MBQ), with field observations for selected links. The following should be kept in mind when making the comparisons of model outputs and field data:

- ✓ The maximum queue length estimated by most models is the maximum physical length of the queue, which occurs just after the beginning of the green.
- ✓ The maximum back of queue is not the queue length at the beginning of the green, but the farthest point the queue extends upstream during the cycle, usually several seconds into the effective green.

If the estimated queue length is significantly different than observed in the field in an average cycle, then the volumes, saturation flows, or signal timing data should be checked.

Delay and Travel Time

The average delay (sec/veh) predicted by the models should be compared with field measurements for a number of representative links (through and left-turn movements). These comparisons should, however, be made with caution, since the definition of delay used in the models may not be the same as the definition used by the measurement technique. For example, TRANSYT estimates the total approach delay for a link. If the average stopped delay is measured in the field, it should be converted to the total delay for comparison with most model estimates.

Another source of error occurs when the link is saturated, since the estimate for random and saturation delay produced by the models may lead to a total estimate which is significantly greater than that measured in the field. For example, comparison of the field measurements with TRANSYT's uniform delay estimate may produce a better result in this case.

Travel time measurements also should be conducted and compared with model estimates (if available) to verify that the model reasonably represents existing condition. Travel times are obtained using floating cars on test routes representing the predominant traffic patterns in the study area. Travel time, including the delay and stops at signals, should be recorded for every link and then compared to the model outputs.

Substantial differences between measured and predicted travel times typically indicate input error in cruise speeds, link volumes, saturation flows and/or signal timing data. Again, travel time estimates may be unrealistic at saturated intersections. In this case, the degree of saturation and the maximum back of queue are better measures of performance for the purpose of model calibration.

8 TIMING PLAN IMPLEMENTATION AND EVALUATION

Proper implementation of the timing plans is crucial to a successful system retiming project. A major component to proper implementation involves a thorough understanding of field equipment, specifically detection and the controller. There is no replacement for experience so this section only touches on implementation.

8.1 Implementation and Field Verification

There are four basic steps in the implementation process as follows:

- ✓ The timing plan must be developed (i.e., output from Synchro)
- ✓ The timing plan must be converted into a form that is compatible with the traffic signal controller
- ✓ The timing plan must be transferred into the traffic signal controller in the field or remotely
- ✓ The timing plan must be fine-tuned in the field

Install timing plan into controller and put plan into operation during an off peak time. Check timing, observe operation and make any necessary changes.

The traffic signal operation should be observed for all time periods serviced by the new timing plans immediately following implementation. Seemingly small errors can have dramatic impact on traffic operations, so new timing plans must be observed in operation. If excessive stops and delays are observed, timing adjustments should be made. It may be necessary to observe the signal operation again after a period of time to allow traffic to stabilize. A series of timing adjustments may be necessary.

8.2 Traffic Controller Timing Inputs

A portion of an Econolite controller manual has been included at the end of this chapter.

Synchro reports many of the parameters required implementing the timing data into the controller. These include:

- ✓ The controller cycle length,
- ✓ The movement split in seconds or percent, and,
- ✓ The reference phase offset.

There are, however, certain checks and calculations that must be performed before implementation into a coordinated system controller unit. These include, but are not limited to:

- ✓ Can the cycle length handle all of the green, clearance, walk, and flashing don't walk intervals?
- ✓ Do all splits satisfy their minimum requirement?
- ✓ Are the permissive periods set correctly (some controllers have the ability to automatically determine the permissive periods)?
- ✓ If coordinated phase split extension is used (see the definition in the Econolite literature), are the remaining phases allocated adequate time?

8.3 Econolite Controller Timing

Data source: Econolite Controller Manual

Offset Change by Smooth Transition

When changing offset by smooth transition, the coordination module establishes a new offset by moving the current offset toward the desired offset by the shortest percentage route possible. This movement will normally not be over 50 percent of the cycle length and will be accomplished by moving the actual offset 1 percent for each 6 percent of the local master cycle length.

Therefore, if the desired offset is changed, the actual offset will equal the desired offset within three local cycle lengths or less. The direction in which the offset is moved is determined by the coordination module by comparing the desired offset to the current offset. If the desired offset is greater than the current offset by no more than 50 percent, the module will move the offset point by adding. This procedure will lengthen the local cycle by a maximum of 20 percent until the desired offset is reached. If the desired offset is less than the current offset or greater by more than 50 percent of the current offset, the module will move the offset point by subtracting 1 percent from the offset for each 6 percent of the cycle length. This will shorten the cycle by a maximum of 16.6 percent until the desired offset is reached.

If the coordination module determines that the offset should be changed by subtracting, it will compare the controller minimum cycle length to the current cycle length in effect to determine if the cycle can be decreased. If decreasing the cycle will shorten the cycle below the controller minimum cycle, the coordination module will force the offset to be changed by adding. This may cause the offset change to take more than three cycle lengths to complete.

It is possible to program the coordination module to inhibit the smooth transition subtract operation. This will result in all offset changes being made by adding time.

Offset Change by Dwell

The coordination module can make offset changes by smooth transition or by dwelling. The option of offset changes by dwelling is selected by programming the dwell to a value other than zero (0). This will inhibit smooth transition and force all offset changes to be made by dwelling in the coordinated phase.

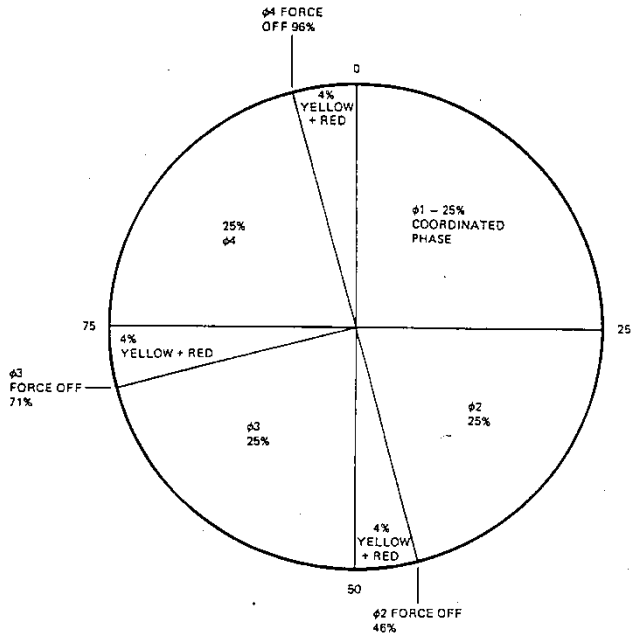
The coordination module will hold the controller in the coordinated phase while dwelling. The period of time that the module will dwell in the coordinated phases is from 1 to 99 percent of the cycle length. After the dwell period the coordinator, will release. the coordinated phases to serve calls. The dwelling operation will then be preempted until the desired offset is reached.

Split

Each of the six cycles of the coordination module will operate in any of four splits. A split is the division of the cycle time period into sections (split intervals) which establish the maximum amount of time that will be allocated to each timing phase (see the figure on the following page). The maximum time allocated to a phase is controlled by the split interval setting for the phase. The coordinator provides a split interval for each phase, including the coordinated phase. The split intervals are numbered from 1 to 8, with the split interval number corresponding to the phase number. Each split interval is variable from 0 to 99 percent of the cycle length. However, the sum of the split intervals for each timing ring of the controller should not exceed 100 percent. In addition, the sum of the split interval for each timing ring of a concurrent group should normally be equal.

Split Intervals

The maximum time allocated to a phase is entered as a percentage of cycle length in the split interval corresponding to the phase. This percentage value should be the total maximum time that the phase will be allowed to time, including yellow and red clearance time. In the example shown in the figure on the following page, each of the four phases has been assigned an equal portion of the cycle. Thus, the split interval entry for each phase will be 25 percent.



SPLIT INTERVAL 1 – ϕ1	25%
SPLIT INTERVAL 2 – ϕ2	25%
SPLIT INTERVAL 3 – ϕ3	25%
SPLIT INTERVAL 4 – ϕ4	25%
SPLIT INTERVAL TOTAL	100%

The coordination module uses the controller's force-off capability to control the maximum time for each phase. Using the split interval value for the phase and the phase yellow and red clearance times, the coordination module establishes a point within the cycle when force off should be applied to terminate the phase, thus limiting the timing of the phase. The coordination module calculates the force-off point according to the following formula:

Force-Off Point = Coordinated phase split interval + phase timing split interval + sum of the split intervals prior to the phase timing - (phase timing yellow + red clearance percent).

Using the example of the figure above, the force-off points will be calculated as follows:

∅2 Force-Off Point = 25% (∅1) + 25% (∅2) - 4% (∅2 clearance)

= 46%

∅3 Force-Off Point = 25% (∅1) + 25% (∅3) + 25% (∅2) - 4% (∅3 clearance)

= 75%

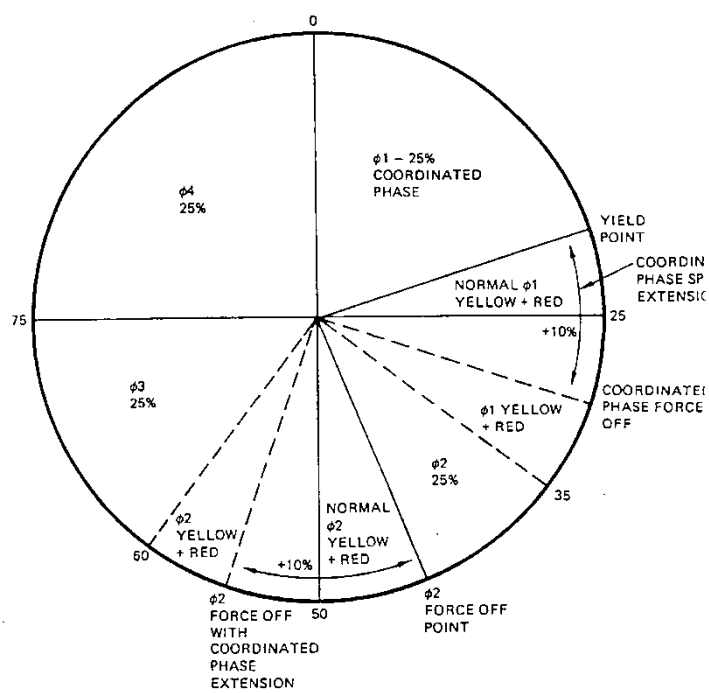
∅4 Force-Off Point = 25% (∅1) + 25% (∅4) + 50% (∅2 + ∅3) - 4% (∅4 clearance)

= 75%

Coordinated Phase Split Extension

The coordination module normally sets the coordinated phases to operate in the nonactuated mode. However, it is possible to program the coordinated phases to operate in the actuated mode. In either mode, the controller is held in the coordinated phases by applying the hold command. This effectively inhibits actuated operation. At the yield point the coordinator removes the hold command, releasing the coordinated phase. If the coordinated phase is actuated, it then can begin extending. The amount of extension is controlled by the coordinated phase split extension interval (split interval 0). At the end of the extension period, the coordinator applies a force off to the coordinated phases, thus causing them to yield to calls on other phases. This operation allows the coordinated phase split to be increased based on traffic demand.

To insure that the remaining phases are allocated a full split interval, the coordinator cycle is modified based on the amount of coordinated phase extension. This is shown in the figure below. In this example the coordinated phase is allowed to extend 10 percent. This makes the end of the coordinated phase from 25 percent to 35 percent. This would normally have been a portion of the phase 2-split interval. Without modifying the cycle this implies that the phase 2 split would be reduced by 10 percent. To prevent this from occurring, the cycle is shifted by the coordinated phase extension. Thus, if there are continuous calls on phase 2 causing the phase to use its full split interval, the phase will now end at 60 percent instead of 50 percent. This same operation also occurs in phases 3 and 4. However, if each phase uses its maximum allotted split time, the split of the last sequential phase will be reduced. The coordinator will try to extend the split of the last phase. However, if it determines that the extension will require the phase to be terminated after local zero, the coordinator will apply force off to the phase at 99 percent. This will normally result in a coordination error causing an offset error. As soon as the controller reenters the coordinated phase, the coordinator will begin a smooth transition or dwell operation to correct the offset error.



The maximum amount that the coordinated phase can extend is controlled by the coordinated phase split extension interval. This can be set from 0 to 99 percent. If the coordinated phase gaps out before the maximum amount, the actual extension amount will be used in extending the split of the other phases.

If the phase following the coordinated phase (phase 2 in the example shown in the figure above) does not have a demand prior to the end of the coordinated phase split extension, the split of the remaining phases will not be extended. This is because the coordinated phase extension did not actually use any of the phase 2 split time, being there was no demand on the phase.

Free to Coordinated Transition

After initial power-on of the controller or after the coordination module has been returned to the remote or coordinated mode following a Free or Remote Flash command, the coordination module remains in the Free mode until a sync pulse is detected. This first sync pulse loads the current coordination commands and starts the local master cycle timer. This pulse also starts a coordination pick-up cycle. During this cycle one detector call is placed on all phases and the controller is allowed to continue running Free. The coordinator then monitors the controller checking for the start of the coordinated phase green interval. When both coordinated phases if a dual ring intersection) have reached the beginning of the green interval, the coordinator places the controller into coordinated operation. This point is used as the first local zero point. The local cycle timer is started and the coordination module begins controlling the controller timing based on the current offset of the local cycle. This pick-up scheme provides a smooth and orderly transition of the intersection into the coordinated system. During the pick-up cycle, the cycle complete display is set to the message UP to indicate that the coordinator is in the pick-up cycle.

Permissive Periods

The coordination module provides two types of permissive period operations. The permissive period controls the time period during which the coordination module releases hold on the coordinated phases, allowing the controller to begin servicing calls on the remaining phases. If a call is not detected during the permissive period, hold is reapplied to the coordinated phases, causing the controller to rest in the coordinated phases until the next permissive period. Permissive period operation always starts at the coordinated phase yield point. This is defined as the point in the local cycle equal to the coordinated phase split interval minus clearance times.

The first type of permissive operation consists of standard single or dual permissive periods that are controlled by operator entries. The second type of permissive operation consists of automatically computed permissive periods for each sequential phase. This method does not require any permissive period data entries by the operator. All permissive periods consist of vehicle and pedestrian periods, with each timing together. The length of the pedestrian period is automatically determined by the walk plus pedestrian clearance timing of the phase being controlled by the period.

Yield Point

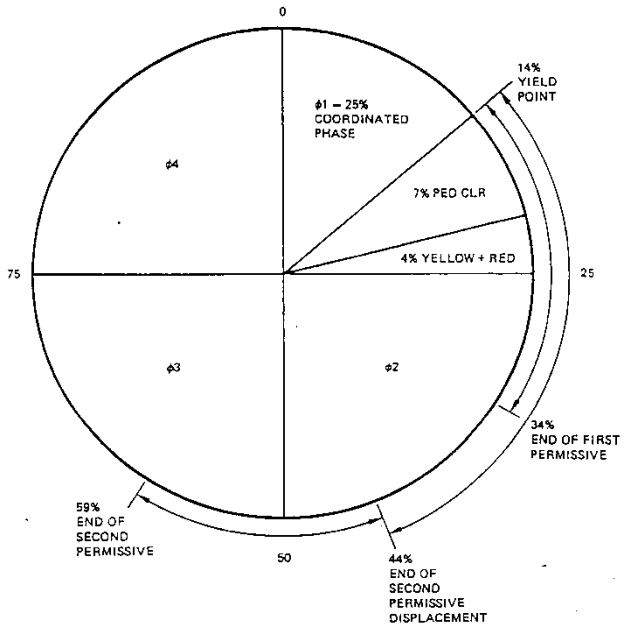
All permissive period timing begins at the yield point. This is the point within the cycle at which the coordination module releases hold on the coordinated phase and allows the controller to begin servicing calls. The yield point is automatically determined by the coordination module based on the coordinated phase split interval and pedestrian and vehicle clearance times. If the coordinated phase is operating as a standard nonactuated phase, the yield point is calculated according to the following formula:

Yield Point = Coordinated phase split interval - (Pedestrian + vehicle clearance time)

Using the example shown in the figure on the following page, the uncoordinated phase 1, yield point is calculated as follows:

Yield Point = 25% - (7+4)%

= 14%



FIRST PERMISSIVE (VP1) = 20%
SECOND PERMISSIVE DISPLACEMENT (VP2D) = 30%
SECOND PERMISSIVE (VP2) = 15%

The yield point calculation changes if the coordinated phase is operating fully actuated. In this case, the coordinated phase pedestrian movement times normally and, thus, is not held at the end of the walk timing. In this case, the yield is calculated according to the following formula:

Yield Point = Coordinated phase split interval - vehicle clearance time

Thus, using the same example of the figure above, if the coordinated phase was actuated, the yield point would be 21 percent instead of 14 percent.

Operator Controller Permissive Periods

The operator controlled permissive periods are variable from 0 to 99 percent of the cycle length and are capable of either dual or single permissive operation.

Dual Permissive Operation

If dual permissive operation is used, the Vehicle Permissive Period 1 and its associated pedestrian permissive period time first. This period always begins timing at the coordinated phase yield point (see the figure above). During this first permissive period, the coordination module allows the controller to serve vehicle or pedestrian calls on only the first phase(s), or B phase, following the coordinated phase. The coordination module determines which phase(s) is the B phase based on the phase sequence programming of the controller configuration PROM and by checking which phases are set to the NO-PHASE mode.

The second permissive period, or Vehicle Permissive Period 2, begins timing at an adjustable time period after the yield point. This period is the Vehicle Permissive Period 2 Displacement and is adjustable from 0 to 99 percent of the cycle length. During the second permissive period, the coordination module allows the controller to serve calls on all remaining phases except the first permissive phase(s). The module applies Phase Omit to the first permissive phase(s) during the second permissive period. The pedestrian permissive period portion of the second permissive period controls the pedestrian calls on the second phase(s), C Phase, following the coordinated phase. The pedestrian calls on the remaining phase(s) of the controller are not controlled.

If the controller yields to a call during the first permissive period, the coordination module allows the controller to serve all remaining phase calls in normal sequence. Thus, if a yield occurs during the first permissive, the second permissive period is inhibited from starting because it is no longer required.

Single Permissive Operation

The second permissive period is capable of being eliminated to give a single permissive period operation. With single permissive operation, only the Vehicle Permissive Period 1 and its associated pedestrian permissive period are timed. Both permissive periods begin timing at the yield point. During the permissive period, the coordination module allows the controller to yield to a call on any phase. The pedestrian permissive period portion of the permissive period, however, only controls the pedestrian call on the first phase following the coordinated phase. Single permissive operation is selected by setting the Vehicle Permissive 2 displacement to zero. The Vehicle Permissive Period 2 setting is then ignored by the coordination module.

Two-Phase Controller Dual Permissive

The coordination module provides a special dual permissive operation in a two-phase controller. (A two-phase controller is any KMC-2/4/3 using only two phases.) During the first permissive period the coordinator checks for calls on the second phase and yields if a call is present. If a call is not present, then the coordinator holds the coordinated phase until the second permissive period starts. It then rechecks calls on the second phase and will allow the controller to yield if a call is present. If the controller yields during the first permissive, the coordinator will not time the second permissive. Thus, the coordinator will only allow the controller to yield once to the second phase.

Pedestrian Permissive

During single or dual permissive operation the pedestrian permissive period is automatically calculated by the coordinator. The period is determined by the walk plus pedestrian clearance and split interval of the phase being controlled. If a pedestrian call is not detected during the pedestrian permissive, the coordinator inhibits pedestrian operation by applying pedestrian omit to the phase. This will be cleared at the next local zero. If the controller yields to a vehicle call during the pedestrian permissive period, pedestrian call will be answered up to the beginning of the phase.

Automatic Permissive Periods

The coordination module is capable of automatically computing permissive periods. In this operation the coordination module assigns each sequential phase a specific vehicle and pedestrian permissive period. The length of the vehicle permissive period is determined by the phase split interval and minimum time. The phase minimum time is equal to the auto permissive minimum green or the phase minimum green time, whichever is larger, plus the yellow and red clearance time. The auto permissive green time allows the phase minimum to be set to a low value but still insures that the auto permissive period provides sufficient green time if the controller yields to the phase at the end of the permissive. This is especially useful on left-turn phases where the minimum is set to zero. An auto permissive green time is provided for each cycle. The pedestrian permissive is determined by split interval and walk, pedestrian clearance, and yellow plus red clearance timing. Automatic permissive operation is selected by setting the value of Vehicle Permissive 1 and Vehicle Permissive 2 Displacement to zero (0). This allows the automatic permissive operation to be selected on a cycle-by-cycle basis. It should be noted that the default permissive operation, after initial turn on of the coordinator, is automatic permissives.

During automatic permissive operation the timing of a permissive period for a phase is determined by the controller's phase sequence (as determined by the configuration PROM and phases set to NO PHASE). The permissive period for the first phase(s) following the coordinated phase times first. If a call is not received within the permissive period, the coordinator applies phase omit to the phase and begins timing the

permissive period for the next sequential active phase(s). This operation continues for each sequential phase(s). This allows a phase to be serviced only within its permissive period. However, if the coordination module yields the controller to a phase, the controller is allowed to service the remaining phases in the normal manner. The automatic permissive periods do, however, continue to time and will inhibit servicing a phase if there is not sufficient time remaining.

Calculating Automatic Vehicle Permissives

All automatic permissive periods begin timing at the yield point. The period of each vehicle permissive is determined by the phase split interval and minimum time. The coordinator calculates the end point of the permissive period according to the following formula:

Vehicle Permissive End Point = Coordinated phase split interval

+ Sum of the split intervals of the permissive phase and all phases prior to it

- Permissive phases minimum time

- Coordinated phase clearance time

+ Coordinated phase extension

Using the example shown in the figure on the following page, the end of phase 2 vehicle permissive will be calculated as follows:

∅2 Vehicle Permissive End Point = 25% (∅1) + 25% (∅2) - 9% - 4%

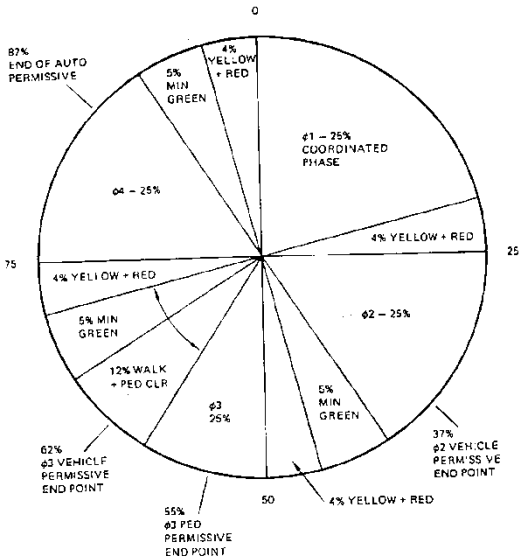
= 37%

Thus, if a phase 2 call is not received prior to the cycle reaching 37 percent, phase 2 will be omitted and the permissive period for phase 3 will start. The end point of the phase 3 vehicle permissive is calculated in a similar manner:

∅3 Vehicle Permissive End Point = 25% (∅1) + 50% (∅2 + ∅3) - 9% - 4%

= 62%

The coordinator continues the permissive timing until the cycle reaches the permissive end point of the last sequential phase or until the controller returns to the coordinated phases. Thus in the example in the figure on the following page, the permissive timing would end when the cycle reached 87 percent.



Calculating Automatic Pedestrian Periods

Each vehicle permissive period has a separate pedestrian permissive period that times concurrently with it. The pedestrian permissive period is the time period during which the controller is allowed to answer pedestrian calls. This period is determined by the walk plus pedestrian clearance and split interval of the phase being controlled. However, the pedestrian permissive can never be longer than the vehicle permissive. If the vehicle permissive ends prior to the end of the pedestrian permissive, the pedestrian permissive is terminated.

If a pedestrian call is not detected during the pedestrian permissive period, the coordination module inhibits the controller from servicing any further pedestrian call by applying pedestrian omit to the phase. This is then cleared at the next local zero. However, if the controller yields to a vehicle call during the pedestrian permissive period, pedestrian calls will be answered up to the beginning of the Vehicle Phase Green.

The coordination module calculates the end point of the pedestrian permissive period according to the following formula:

Pedestrian Permissive End Point = Coordinated phase split interval

+ Sum of the split intervals of the permissive phase and all phases prior to it

- Permissive phases walk time + pedestrian clearance + yellow + red time

- Coordinated phase clearance time

Using the example of the figure above, the phase 3 pedestrian permissive end point is calculated as follows:

∅3 Pedestrian Permissive End Point = 25% (∅1) + 75% (∅2 + ∅3) - (12 + 4) - 4%

= 55%

Thus, when the cycle reaches 55 percent, pedestrian omit would be applied to phase 3 unless a pedestrian call was present.

8.4 Post Implementation Evaluation

Field evaluation of new timing plans is substantially more complicated than the estimating of benefits from computer outputs, but it is more significant because it is physical "proof". Such field verification of benefits is often necessary to justify the cost of signal optimization projects.

Field evaluation is a complex task requiring careful planning, execution, and analysis. Evaluations are typically "before" vs. "after" in nature and are usually conducted through floating car techniques. Typical measures of effectiveness include travel time, or delay, and number of stops. Fuel consumption is also sometimes measured, although it is difficult to accurately measure fuel consumption in the field. A sufficient number of floating car runs must be made to be representative of the traffic movements in the system to assure that, if statistically improvements exist, they can be measured at a reasonable level of confidence. Measured benefits can be translated into monetary values, compared with the sum of capital costs and any recurring maintenance costs in order to determine cost-effectiveness.

Field Conditions

Since the objective of a field evaluation is to test the performance of the new timing plan, the conditions in the project area should be as identical as possible in the existing condition (i.e., "before" condition) and those expected after the new timing plans are implemented (i.e., "after" condition). Unrelated design changes in the system, such as adding a lane or a left-turn bay, or traffic management schemes should be avoided. These changes could affect the results obtained in the field, possibly leading to inconclusive statements about the performance of the implemented timing plan.

Since measurable improvements to the traffic operations could potentially result in the system attracting additional traffic from parallel congested systems, field measurements for the "after" condition should be conducted as soon as possible after the timing plans have been implemented and fine-tuned. That is, an acclimation period intended to allow traffic stabilize is not necessary and is not recommended. The data collection schedule should also be planned to avoid any activities that change the normal traffic patterns in the project area. Common examples include holidays, return to school, street blockages from construction work, etc.

Data Collection Periods

Field data on system performance should be collected at the same times of the day that were modeled. For example, if signal timing plans were developed for the AM peak, off-peak and PM peak, the test periods for field data collection should be identical so that the implemented timing plans correspond to the traffic patterns at those times. This requirement applies to field measurements for both the "before" and "after" conditions.

Duration of Data Collection

The time required for data collection varies with the number of signals in the system, the number of timing plans, available personnel and equipment, and other considerations particular to the specific system. Ideally, you should plan to collect data for two weeks, 3-5 days a week, for both the "before" and "after" conditions. This would ensure a minimum of 8-10 days of good data. An even longer period might be needed if unusual traffic conditions occur in the system, or if other circumstances degrade the quality of the data collected.

Resource constraints may necessitate cutting back the data collection period to one week before and one week after. This will naturally reduce the degree of confidence you will have in the evaluation.

Measures of Effectiveness

The specific MOEs recommended to be measured in the field evaluation are travel time and stops. Travel time is preferred to delay because it takes into account the improvements in mid-block travel due to improved progression. It is also easier to measure.

Manual field data should be recorded on log sheets. If computerized data collection methods are used, the MOEs will be automatically recorded by the system. For manually collected travel time data, only the "cumulative travel time" needs to completed in the field. The link travel times may then be computed in the office by subtracting the cumulative travel time at the beginning of the link from the corresponding value at the end of the link. The cumulative time in the system is also computed in the office by removing travel times on links that are outside of the system (i.e., exit/entry links). The total cumulative times in the system should be averaged and compared to give an assessment of the improvement.

Sample Size Requirements

Ideally, only the timing plan would vary between the "before" condition and the "after" condition. However, traffic measurements will generally vary by time of day, day of week, car type, driver, etc. Effort should be made to minimize this variation by using the same car and driver in each case and collecting data under similar conditions. To help overcome these variations, the sample size should be adequate and should be set to provide a level of confidence of not less than 80%. Note that different MOEs may require different sample sizes.

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Appendix A. Glossary of Signal Timing Terms

ACTIVE WARNING SYSTEM FOR A RAILROAD GRADE CROSSING (ACTIVE WARNING DEVICES) - the railroad flashing light signals with or without warning gates, together with the necessary control equipment used to inform road users of the approach or presence of trains at highway-railroad grade crossings.

ADVANCE PREEMPTION - notification of an approaching train is forwarded to the traffic signal controller unit by the railroad equipment for a period of time prior to the activation of railroad active warning devices.

ADVANCED WARNING FLASHER (AWF) - an advanced warning device located on main street approaches to a high speed signalized intersection, which can provide advanced warning to the motorists on the main street that the traffic signal system will be turning yellow during their approach.

AUXILIARY EQUIPMENT - Separate devices used to add supplementary features to a controller assembly.

BARRIER - A barrier (compatibility line) is a reference point in the preferred sequence of a multi-ring controller unit at which all rings are interlocked. Barriers assure there will be no concurrent selection and timing of conflicting phases for traffic movements in different rings. All rings cross the barrier simultaneously to select and time phases on the other side.

BIU - A module used to interface the controller with the field terminals and detector loops in a TS2 cabinet.

CABINET - An outdoor enclosure for housing the controller unit and associated equipment.

CALL - A registration of a demand for right-of-way by traffic (vehicles or pedestrians) to a controller unit.

Serviceable Conflicting call:

- Occurs on a conflicting phase not having the right-of-way at the time the call is placed.
- Occurs on a conflicting phase which is capable of responding to a call.
- When occurring on a conflicting phase operating in an occupancy mode, remains present until given its right-of-way.

CHECK - An output from a controller unit that indicates the existence of unanswered call(s).

CLEAR STORAGE DISTANCE - The distance available for vehicle storage measured between 6 feet (2 meters) from the rail nearest the intersection to the intersection STOP BAR or the normal stopping point on the highway. At skewed crossings and intersections, the 6 feet (2 meters) distance will be measured perpendicular to the nearest rail either along the centerline, or edge line of the highway as appropriate to obtain the shorter clear distance.

CLEAR TRACK GREEN INTERVAL - the time assigned to clear stopped vehicles from the track area on the approach to the signalized intersection (Also see Track Clearance Phase Time).

CONCENTRATION - The largest of Scaled Occupancy or Scaled Volume expressed in percent.

CONFIRMATION LIGHTS - Indicator lights mounted on the mast arms confirm that preemption is in operation, when an authorized emergency vehicle approaching an EVP-equipped signalized intersection enroute and making a call for preemption.

CONNECTOR - A device enabling outgoing and incoming electrical circuits to be connected and disconnected without the necessity of installing and removing individual wires leading from the control unit.

- Not Used Connections - The “Not Used” connector pin termination’s are used exclusively to prevent interchangeability with units already in use not in conformance to this publication. These connector pins are not to be internally connected.

- Reserved Connections - The "Reserved" connector pin termination are used exclusively for future assignment by NEMA of additional specific input/output functions. The control unit does not recognize any "reserved" input as valid nor shall it provide a valid output on a "Reserved" output.
- Spare Connections - The "Spare" connector pin termination are exclusively for manufacturer specific applications. A controller Assembly wired to utilize one of these connections may not be compatible with all manufacturer's control units.

CONTROLLER ASSEMBLY - A complete electrical device mounted in a cabinet for controlling the operation of a traffic control signal.

CONTROLLER UNIT - A controller unit is that portion of a controller assembly that is devoted to the selection and timing of signal displays.

- Digital Controller Unit - A controller unit wherein timing is based upon a defined frequency source such as a 60-hertz alternating current source.
- Multi-ring Controller Unit - A multi-ring controller unit contains two or more interlocked rings which are arranged to time in a preferred sequence and to allow concurrent timing of all rings, subject to the restraint on BARRIER.
- Single-Ring controller unit - A single-ring controller unit contains two or more sequentially timed and individually selected conflicting phases so arranged as to occur in a established order.

COORDINATION - The control of controller units in a manner to provide a relationship between specific green indications at adjacent intersections in accordance with a time schedule to permit continuous operation of groups of vehicles along the street at a planned speed.

COORDINATOR - A device, program or routine which provides coordination.

CRITICAL PHASE MOVEMENT - The longest of either the Pedestrian Clearance Interval, the Minimum Green Interval, or Leading Flash Time of AWF (if present).

CYCLE - A complete sequence of signal indications for all phases.

CYCLE - The total time to complete one sequence of signalization around an intersection. In an actuated controller unit, a complete cycle is dependent on the presence of calls on all phases. In a pretimed controller unit unit it is a complete sequence of signal indications.

CYCLE LENGTH - The time period in seconds required for one complete cycle.

DENSITY - A measure of the concentration of vehicles, stated as the number of vehicles per mile per lane.

DESIGN VEHICLE - the longest vehicle permitted by the road authority on a roadway.

DETECTION -

- ✓ Advisory Detection - The detection of vehicles on one or more intersection approaches solely for the purpose of modifying the phase sequence and/or length for other approaches to the intersection.
- ✓ Passage Detection - The ability of a vehicle detector to detect the passage of a vehicle moving through the zone of detection and to ignore the presence of a vehicle stopped within the zone of detection.
- ✓ Presence Detection - The ability of a vehicle detector to sense that a vehicle, whether moving or stopped, has appeared in its zone of detection.
- ✓ Zone of Detection - The area or zone that a vehicle detector can detect a vehicle.

DETECTOR - A device for indicating the presence or passage of vehicles or pedestrians.

- ✓ Bi-directional Detector - A detector that is capable of being actuated by vehicles proceeding in either of two directions and of indicating in which of the directions the vehicles were moving.
- ✓ Calling Detector - A registration of a demand during red interval for right-of-way by traffic (vehicles or pedestrians) to a controller unit.
- ✓ Classification Detector - A detector that has the capability of differentiating among types of vehicles.
- ✓ Directional Detector - A detector that is capable of being actuated only by vehicles proceeding in one specified direction.
- ✓ Extension Detector - A detector that is arranged to register an actuation at the controller unit only during the green interval for that approach so as to extend the green time of the actuating vehicles.
- ✓ Infrared Detector - A detector that senses radiation in the infrared spectrum.
- ✓ Light-Sensitive Detector - A detector that utilizes a light-sensitive device for sensing the passage of an object interrupting a beam of light directed at the sensor.
- ✓ Loop Detector - A detector that senses a change in inductance of its inductive loop sensor by the passage or presence of a vehicle near the sensor.
- ✓ Magnetic Detector - A detector that senses changes in the earth's magnetic field caused by the movement of a vehicle near its sensor.
- ✓ Magnetometer Detector - A detector that measures the difference in the level of the earth's magnetic forces caused by the passage or presence of a vehicle near its sensor.
- ✓ Nondirectional Detector - A detector that is capable of being actuated by vehicles proceeding in any direction.
- ✓ Pedestrian Detector - A detector that is responsive to operation by or the presence of a pedestrian.
- ✓ Pneumatic Detector - A pressure-sensitive detector that uses a pneumatic tube as a sensor.
- ✓ Pressure-Sensitive Detector - A detector that is capable of sensing the pressure of a vehicle passing over the surface of its sensor.
- ✓ Radar Detector - A detector that is capable of sensing the passage of a vehicle through its field of emitted microwave energy.
- ✓ System Detector - Any type of vehicle detector used to obtain representative traffic flow information.
- ✓ Side-Fire Detector - A vehicle detector with its sensor located to one side of the roadway.
- ✓ Sound-Sensitive Vehicle Detector - A detector that responds to sound waves generated by the passage of a vehicle near the surface of the sensor.
- ✓ Ultrasonic Detector - A detector that is capable of sensing the passage or presence of a vehicle through its field of emitted ultrasonic energy.
- ✓ Video Detection - A detector that is responds the Video image or changes in the Video image of a vehicle.

<u>DETECTOR MODE</u> - A term used to describe the operation of a detector channel output when a presence detection occurs.

- ✓ Pulse Mode - Detector produces a short output pulse when detection occurs.
- ✓ Controlled Output - The ability of a detector to produce a pulse that has a predetermined duration regardless of the length of time a vehicle is in the zone of detection.
- ✓ Continuous-Presence Mode - Detector output continues if any vehicle (first or last remaining) remains in the zone of detection.
- ✓ Limited-Presence Mode - Detector output continues for a limited period of time if vehicles remain in zone of detection.

<u>DEVICE -</u>

- ✓ Electromechanical Device - A device which is characterized by electrical circuits utilizing relays, step switches, motors, etc.
- ✓ Electronic Device - A device which is characterized by electrical circuits utilizing vacuum tubes, resistors, capacitors and inductors, and which may include electromechanical components and solid state devices.
- ✓ Solid State Device - A device which is characterized by electrical circuits, the active components of which are semi-conductors, to the exclusion of electromechanical devices or tubes.

DIAL - The cycle timing reference or coordination input activating same. Dial is also frequently used to describe the cycle.

DISSIPATION OF QUEUED VEHICLES, PER LANE - This is the time needed to allow all vehicles stored between the rail crossing stop line and the signalized intersection to move forward and clear the intersection. This should be used when the railroad tracks are close to the roadway. The time to clear a queue of passenger cars can be estimated by the following formula: $t = 4 + 2n$; where t is the time to clear the queue in seconds, n is the number of vehicles in the queue per lane. This formula assumes that all the queued vehicles can accelerate at, or close to, the rate of passenger vehicles.

DWELL - The interval portion of a phase when present timing requirements have been completed.

EARLY RELEASE - A term used to describe the servicing of a coordinated phase in advance of its programmed begin time as a result of unused time from non-coordinated phases.

EMERGENCY VEHICLE PREEMPTION (EVP) - A system installed on authorized emergency vehicles and at traffic signals which allows the authorized emergency vehicles to travel through signalized intersections in a safe and timely manner. A typical system works as follows: An authorized emergency vehicle approaching a signalized intersection enroute to a call has an activated emitter (a strobe light oscillating at a specified frequency). The oscillations are detected by an EVP detector mounted on the signal mast arm. The signal controller terminates any conflicting phases to bring up the through phase for the authorized emergency vehicle. Indicator lights mounted on the mast arms indicate that preemption is in operation. An optional system can respond to vehicle sirens, using the siren as the emitter and a microphone array as the detector. This system is allowable when requested by local agencies, but only outside of the eight-county metro area. This system must be specified in the project plans and specifications, and must be pre-approved by MnDOT.

ENTRY -

- ✓ Dual Entry - Dual entry is a mode of operation (in a multi-ring controller unit) in which one phase in each ring must be in service. If a call does not exist in a ring when it crosses the barrier, a phase is selected in that ring to be activated by the controller unit in a predetermined manner.
- ✓ Single Entry - Single entry mode of operation (in multi-ring controller unit) in which a phase in one ring can be selected and timed alone if there is no demand for service in a nonconflicting phase on parallel ring(s).

EQUIPMENT RESPONSE - The time for a traffic signal controller to respond. Less than a second for most traffic signal controllers. Check controller manufacturers.

EXTENSION UNIT - The timing interval during the extensible portion which is resettable by each detector actuation. The green interval of the phase may terminate on expiration of the unit extension time.

FLASHER - A device used to open and close signal circuits at a repetitive rate.

FLASHER CONTROLLER ASSEMBLY - A complete electrical device for flashing a traffic signal or beacon.

FLASHERS INTERVAL - Interval from the time the railroad flashers begin flashing to the time the train arrives at the crossing. This time must be equal to or greater than the minium 20 seconds required by the MN

MUTCD. The MN MUTCD states that, circuits controlling automatic flashing light signals shall provide for a minimum operation of 20 seconds before the arrival of any train on such track.

FLASHING LIGHT SIGNAL - the signal at rail crossing display toward approaching highway traffic the aspect of two red lights in a horizontal line flashing alternately when indicating the approach or presence of a train.

FLASHING YELLOW ARROW INDICATION - The Flashing Yellow Arrow (FYA) head is a signal that uses a flashing yellow arrow indication for permissive left turns instead of using a green ball. It is a 4-section FYA signal head with a red arrow on top, followed by a steady yellow arrow, a flashing yellow arrow, and then a green arrow on the bottom.

FORCE OFF - A command to force the termination of the Green extension in actuated mode or Walk Hold in the nonactuated mode of the active phase. Termination is subject to presence of a serviceable conflicting call.

FULL-TRAFFIC-ACTUATED CONTROLLER ASSEMBLY - A type of traffic-actuated controller assembly in which means are provided for traffic actuation on all approaches to the intersection.

- ✓ Isolated Controller Assembly - A controller assembly for operating traffic signals not under master supervision.
- ✓ Master Controller Assembly - A controller assembly for supervising a system of secondary controller assemblies.
- ✓ Master-Secondary Controller Assembly - A controller assembly operating traffic signals and providing supervision of other secondary controller assemblies.
- ✓ Occupancy Controller Assembly (Lane-Occupancy Controller or Demand Controller, and Presence Controller) - A traffic-actuated controller which responds to the presence of vehicles within an extended zone of detection.
- ✓ Pedestrian-Actuated Controller Assembly - A controller assembly in which intervals, such as pedestrian WALK and clearance intervals, can be added to or included in the controller cycle by the actuation of a pedestrian detector.
- ✓ Pretimed Controller Assembly - A controller assembly for the operation of traffic signals with predetermined:
- ✓ Fixed cycle length(s).
- ✓ Fixed interval duration(s).
- ✓ Interval sequence(s).
- ✓ Secondary Controller Assembly (slave) - A controller assembly which operates traffic signals under the supervision of a master controller assembly.
- ✓ Semi-Traffic Actuated Controller Assembly - A type of traffic-actuated controller assembly in which means are provided for traffic actuation on one or more but not all approaches to the intersection.
- ✓ Traffic-Actuated Controller Assembly - A controller assembly for supervising the operation of traffic control signals in accordance with the varying demands of traffic as registered with the controller by detectors.

GAP REDUCTION - A feature whereby the “unit extension” or allowed time spacing between successive vehicle actuation’s on the phase displaying the green in the extensible portion of the interval is reduced.

HOLD - A command that retains the existing Green interval.

INTERCONNECTION - in the context of this document, the electrical connection between the railroad active warning system and the traffic signal controller assembly for the purpose of preemption.

INTERCONNECT - A means of remotely controlling some or all of the functions of a traffic signal.

INTERVAL - The part or parts of the signal cycle during which signal indications do not change.

- ✓ Minimum Green Interval - The shortest green time of a phase. If a time setting control is designated as “minimum green,” the green time shall be not less than that setting.
- ✓ Pedestrian Clearance Interval - The first clearance interval for the pedestrian signal following the pedestrian WALK indication.
- ✓ Red Clearance Interval - A clearance interval which may follow the yellow change interval during which both the terminating phase and the next phase display Red signal indications.
- ✓ Sequence, Interval - The order of appearance of signal indications during successive intervals of a cycle.
- ✓ Yellow Change Interval - The first interval following the green interval in which the signal indication for that phase is yellow.

INTERVAL SEQUENCE - The order in which signal intervals occur during a phase.

LEADING FLASH TIME OF AWF - the amount of time the Advanced Warning Flasher is operating prior to the yellow phase.

LIGHT RAIL TRANSIT (LRT) - a type of electric transit railway with a "light volume" traffic capacity compared with "heavy rail." Light rail may be on exclusive, semi-exclusive or nonexclusive right-of-way, high or low platform loading, multi-car trains, single cars, automated or manually operated.

MANUAL -

- ✓ Manual Operation - The operation of a controller assembly by means of a hand- operated device(s). A push-button is an example of such a device.
- ✓ Manual Push-button - An auxiliary device for hand operation of a controller assembly.

MAXIMUM GREEN - The maximum green time with a serviceable opposing actuation, which may start during the initial portion.

MAXIMUM PREEMPTION TIME - The maximum amount of time needed following initiation of the preemption sequence for the traffic signals to complete the entire sequence and clear the minimum track clearance distance of any vehicles prior to the arrival of the train at the crossing. This is the total of Right-of-Way Transfer Time, Track Clearance Phase Time, and Separation Time. This time should equal to or greater than the Railroad Warning Time.

MEMORY -

- ✓ Detector Memory - The retention of a call for future utilization by the controller assembly.
- ✓ EPROM - Read-Only, non-volatile, semiconductor memory that is erasable (via ultra-violet light) and reprogrammable.
- ✓ FEPROM - Read-Only, non-volatile, semiconductor memory that is electrical erasable reprogrammable.
- ✓ Nonlocking Memory - A mode of actuated-controller-unit operation which does not requiredetector memory.
- ✓ Non-Volatile Memory - Read/Write memory that is capable of data retention during periods when AC power is not applied for a minimum period of 30 days.
- ✓ PROM - Read-Only, non-volatile, semiconductor memory that allows a program to reside permanently in a piece of hardware.
- ✓ RAM - Semiconductor Read/Write volatile memory. Data is lost if power is turned off.
- ✓ ROM - Read-Only, non-volatile, semiconductor memory manufactured with data content, permanently stored.

- ✓ Volatile Memory - Read\Write memory that loses data when power is removed.

MINIMUM GREEN ON CONFLICTING PHASE - The longest Minimum Green on a non-clear track phase. On many traffic signal controllers the minimum green can be shortened during preemption. A Minimum Green of less than 10 seconds should not be used on high speed approaches.

MINIMUM TRACK CLEARANCE DISTANCE - For standard two quadrant railroad warning devices, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured either from the railroad stop line, warning device, or 12 feet (4 meters) perpendicular to the track centerline, to 6 feet (2 meters) beyond the track(s) measured perpendicular to the far rail, along the centerline or edge line of the highway, as appropriate, to obtain the longer distance.

MMU - A device used to detect and respond to improper and conflicting signals and improper operating voltages in a traffic control system.

MODULAR DESIGN - A device concept such that functions are sectioned into units which can be readily exchanged with similar units.

NTCIP - National Transportation Control ITS Communication Protocol.

OCCUPANCY -

- ✓ Actual - The percent of time that vehicles passing a point occupy the roadway during a period in time. Typically expressed in Percent of occupied per Hour or Vehicles per Hour per Lane.
- ✓ Scaled - The percentage that the Actual Occupancy when compared to a stated maximum. The stated maximum is considered to be 100% use of the roadway.

OFFSET - Offset is the time relationship, expressed in seconds or percent of cycle length, determined by the difference between a defined point in the coordinated green and a system reference point.

OMIT PHASE (Special Skip, Force Skip) - A command that causes omission of a selected phase.

OVERLAP - A Green indication that allows traffic movement during the green intervals of and clearance intervals between two or more phases.

PASSAGE TIME - The time allowed for a vehicle to travel at a selected speed from the detector to the stop line.

PATTERN - A unique set of coordination parameters (cycle, value, split values, offset value, and sequence).

PEDESTRIAN CLEARANCE TIME - the time interval provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the farthest traveled lane or to a median of sufficient width for pedestrians to wait. The longest pedestrian clearance interval on the non-track clear phase should be used. Some signal controllers include the WALK as part of the preemption, check with signal controller manufacturer. the MN MUTCD allows the Pedestrian Clearance to be shortened during preemption if needed. This should be considered a temporary action. If decreasing the pedestrian clearance is required, the roadway agency must work with the railroad company to increase the time to provide the proper pedestrian safety.

PHASE -

- ✓ Traffic Phase - Those green, change and clearance intervals in a cycle assigned to any independent movement(s) of traffic.
- ✓ Conflicting Phases - Conflicting phases are two or more traffic phases which will cause interfering traffic movements if operated concurrently.
- ✓ Nonconflicting Phase - Nonconflicting phases are two or more traffic phases which will not cause interfering traffic movements if operated concurrently.

- ✓ Pedestrian Phase - A traffic phase allocated to pedestrian traffic which may provide a right-of-way pedestrian indication either concurrently with one or more vehicular phases, or to the exclusion of all vehicular phases.
- ✓ Phase Sequence - A predetermined order in which the phases of a cycle occur.
- ✓ Parent Phase - A traffic phase with which a subordinate phase is associated.
- ✓ Vehicular Phase - A vehicular phase is a phase which is allocated to vehicular traffic movement as timed by the controller unit.

PHASE SEQUENCE - The order in which the traffic phases occur during a cycle.

PORTION -

- ✓ Extensible Portion - That portion of the green interval of an actuated phase following the initial portion which may be extended, for example, by traffic actuation.
- ✓ Initial Portion - The first timed portion of the green interval in an actuated controller unit:
- ✓ Fixed Initial Portion: A preset initial portion that does not change.
- ✓ Computed Initial Portion: An initial portion which is traffic adjusted.
- ✓ Maximum Initial Portion: The limit of the computed initial portion.
- ✓ Minimum Initial Portion: (See "Fixed Initial Portion.")
- ✓ Added Initial Portion: An increment of time added to the minimum initial portion in response to vehicle actuation.
- ✓ Interval Portion - A discrete subdivision of an interval during which the signals do not charge.

PREEMPTION - The transfer of the normal control of signals to a special signal control mode for the purpose of servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage, and other special tasks, the control of which require terminating normal traffic control to provide the priority needs of the special task.

PREEMPTOR, TRAFFIC CONTROLLER - A device or program/routine which provides preemption.

PREFERRED SEQUENCE - Normal order of phase selection within a ring with calls on all phases.

PREEMPTION - the transfer of normal operation of signals to a special control mode. Signals are commonly preempted by trains or by emergency vehicles.

PRE-SIGNAL - Supplemental highway traffic signal faces operated as part of the highway intersection traffic signals, located in a position to control traffic approaching the railroad crossing and intersection. The signal faces control vehicles in advance of the railroad tracks and their operation shall be integrated into the railroad preemption program. The signal faces may be located on either the near or far side of the railroad tracks, including mounting on the same cantilever signal structure(s) as the railroad active warning devices.

PRIORITY CONTROL - a means by which the right-of-way is obtained or modified.

PROGRESSION - The act of various controller units providing specific green indications in accordance with a time schedule to permit continuous operation of groups of vehicles along the street at a planned speed.

QUEUE CLEARANCE TIME - the time required for the design vehicle stopped with its nose at the start of the minimum track clearance distance to start up and move far enough to clear its tail end from the minimum track clearance distance. If pre-signals are present, this time should be long enough to allow the vehicle to move through the intersection, or clear the tracks if there is sufficient clear storage distance. If the crossing is a significant distance from the intersection it may not be necessary to clear all of the vehicles through the intersection. The time interval necessary to allow a vehicle to move from the track area to a safe location can be determined by summing the values of the following: the time needed for the vehicle ahead to begin

to move out of the way (t1) and the time needed for a design vehicle in a standing queue to accelerate and move off the tracks (t2).

The time before a vehicle ahead begins to move can be estimated by:

$$t_1 = 2+1.4n$$

where t1, is the time (in seconds) it takes for the vehicle to begin moving and n is the number of vehicles queued ahead of the critical vehicle (n = distance/20 feet).

The time a design vehicle takes to transverse the tracks:

$$t_2 = \sqrt{\frac{2(L+D)}{a}}$$

where t_2 = time (seconds) required for the design vehicle to accelerate to a position of safety once the queue in front of it has begun to move;

L = length of the design vehicle(feet);

D = minimum track clearance distance (feet);

a =acceleration of the passenger design vehicle.

(passenger design vehicle, 4.4 ft/sec2;

SU (Single Unit Truck) design vehicle, 2.5 ft/sec2;

MU (Multiple Unit Truck) design vehicle, 1.6 ft/sec2)

RAILROAD WARNING TIME - Interval from the time the traffic signal controller is notified that a train is approaching to the time the train arrives at the crossing. This interval must be greater than or equal to the time required by the Maximum Preemption Time.

RED CLEARANCE INTERVAL - A clearance interval, which follows the yellow change interval, during which both the terminating phase and the next right-of-way phase display a red indication.

RED CLEARANCE - The longest red clearance interval on a non-clear track phase.

RED INDICATION, MINIMUM (Red Revert) - Provision within the controller unit to assure a minimum Red signal indication in a phase following the Yellow change interval of that phase.

REST - The interval portion of a phase when present timing requirements have been completed.

RIGHT-OF-WAY TRANSFER TIME - the sum of the Equipment Response time, Critical Phase Movement time, the Yellow Change Interval, and the Red Clearance Interval, if these last two are not included in the Pedestrian Clearance Time. This is the worst case time required before the controller can begin servicing the track clear phase.

RING - A ring consists of two or more sequentially timed and individually selected conflicting phases so arranged as to occur in an established order.

SCLC - A protocol for transfer of data between the controller, MMU and BIUs in a TS2 cabinet.

SEPARATION TIME - The time during which the minimum track clearance is clear of vehicular traffic prior to the arrival of the train, typically 4 - 8 seconds. The Separation Time is particularly important when:

(1) The railroad tracks are relatively far from the intersection (a long queue needs to be cleared).

(2) High train speeds.

(3) High percentage of trucks and buses in traffic.

SIGNAL - A device which is electrically operated by a controller assembly and which communicates a prescribed action (or actions) to traffic.

SPEED - The speed of vehicles passing a point in the roadway during a period in time. Typically expressed in Average Miles per Hour or Average Miles per Hour per Lane.

SUPPRESSORS -

- ✓ Suppressor, Radio Interference - A device inserted in the power line in the controller assembly (cabinet) that reduces the radio interference.
- ✓ Suppressor, Transient - A device which serves to reduce transient over-voltages.

SPLIT - The segment of the cycle length allocated to each phase or interval that may occur (expressed in percent or seconds). In an actuated controller unit, split is the time in the cycle allocated to a phase. In a pretimed controller unit, split is the time allocated to an interval.

SWITCH -

- ✓ Auto/Manual Switch - A device which, when operated, discontinues normal signal operation and permits manual operation.
- ✓ Flash Control Switch - A device which, when operated, discontinues normal signal operation and causes the flashing of any predetermined combination of signal indications.
- ✓ Power Line Switch (Disconnect Switch) - A manual switch for disconnecting power to the controller assembly and traffic control signals.
- ✓ Recall Switch - A manual switch which causes the automatic return of the right-of-way to its associated phase.
- ✓ Signal Load Switch - A device used to switch power to the signal lamps.
- ✓ Signal Shut-Down Switch - A manual switch to discontinue the operation of traffic control signals without affecting the power supply to other components in the controller cabinet.

TERMINALS, FIELD - Devices for connecting wires entering the controller assembly.

TIME BASE CONTROL - A means for the automatic selection of modes of operation of traffic signals in a manner prescribed by a predetermined time schedule.

TIMING -

- ✓ Analog Timing - Pertaining to a method of timing that measures continuous variables, such as voltage or current.
- ✓ Concurrent Timing - A mode of controller unit operation whereby a traffic phase can be selected and timed simultaneously and independently with another traffic phase.
- ✓ Digital Timing - Pertaining to a method of timing that operates by counting discrete units.
- ✓ Timing Plan - The Split times for all segments (Phase/Interval) of the coordination cycle.

TRAIN DETECTION INTERVAL - Interval from the time the train is first detected to the time the train arrives at the crossing. This time must be equal to or greater than the time required by the Maximum Preemption Time. Depending on the type of train detection being used the railroad flashers may not begin flashing when the train is detected.

TRACK CLEARANCE PHASE TIME - Either the Dissipation of Queued Vehicles per lane or Queue Clearance Time. If the railroad crossing is a significant distance from the intersection, it may not be necessary to clear all of the vehicles through the intersection, and Queue Clearance Time will be used.

TRAFFIC PHASE - The assignment of right-of-way, change clearance intervals to a traffic movement or group of traffic movements.

TRAFFIC SIGNAL SYSTEM - A group of traffic signals interconnected to provided synchronized operation.

VOLUME -

- ✓ Actual - The count of vehicles passing a point in the roadway during a period in time. Typically expressed in Vehicles per Hour or Vehicles per Hour per Lane.
- ✓ Scaled - The percentage that the Actual Volume is when compared to a stated maximum. The stated maximum is considered to be 100% use of the roadway.

YELLOW CHANGE INTERVAL - The first interval following the green right-of-way interval in which the signal indication for that phase is yellow.

YIELD - A command which permits termination of the green interval.

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Appendix D. Metro Checklists

MnDOT METRO - CHECK LIST FOR FIELD IMPLEMENTATION OF COORDINATION TIMING PLANS

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MnDOT Metro - Checklist for Consultant Signal Optimization Projects

(last updated: 5/30/2015)

1. Use Peak 15 min * 4 Volumes in Volume Window with PHF of 1.0

- We use this for calculating the number of cars on the worst possible cycle so we like to see inflated numbers in the timing window which we use to determine split times for any given cycle.

2. Correct Phase Numbers and Phasing in Timing Window

- Double-check all phase numbers and phasing in the Synchro Files to make sure they are correct based on the plan sheets as it's a pain to change things in the field when implementing the timing.

3. Prot/Permissive Lefts

- Don't allow lagging with permissive lefts in both directions in "Allow lead/lag?" in Timing Window of Synchro

- Do allow lagging at T-intersections and left turns only in one direction (e.g. ramps)

- We don't like to omit the left turn phase on a 5-section head unless it is a shared lane situation, but we will be open to omitting the left turn phase in prot/permissive operation for Flashing Yellow Arrow heads.

4. Need C-Max in Timing Window for Coordinated Phases

- Make sure C-Max is selected in the Timing Window or else Synchro won't match how the signal controller refers to offsets

5. Minimum Splits

- We want the minimum splits 8 sec greater than the min green time. This is because the controller needs to fit in the coordinated clearance (not the phase clearance) and ph. 2 &

6 yellow+all-red are rarely over 7.5 sec. It's also nice to have a 1 sec cushion so 8 sec greater than the min green time has worked well.

- ✓ Mainline 28 sec (assuming 20 sec min green) – Note: Make sure the Max Initial time in the controller is not greater than your lowest mainline split
- ✓ Cross St. 15 sec (assuming 7 sec min green)
- ✓ Split Phase 15 sec (assuming 7 sec min green)
- ✓ Protected Lefts 15 sec (assuming 7 sec min green)
- ✓ Prot/Perm Lefts 13 sec (assuming 5 sec min green)

6. Choosing Cycle Lengths

- Synchro often chooses a cycle length that is too short so you may need to increase the cycle length from 10-30 sec in order to get the cushion you need for the mainline green time. Check the amount of green time needed for the mainline through phases (using the 3+2n procedure described below) and make sure there is at least 10 sec of cushion unless the intersection is very overcapacity. If the intersection is very overcapacity, try to get the split equal to the amount of green time needed if you can.

- Look at various cycle lengths that are close to each other to see if progression in both directions is improved by a particular cycle length as the spacing of the intersections may favor a certain cycle length.

7. Cutting Splits (3+2n Procedure)

- ✓ For each timing plan, divide 3600 by the cycle length to get the number of cycles per hour.
- ✓ Take the volume (peak 15 min volume * 4) and divide by the number of cycles per hour to get an average number of vehicles expected each cycle for the peak 15 minutes.
- ✓ Using the formula 3 + 2n, where n=avg number of vehicles per cycle as calculated in step 4, determine the amount of green time needed for the movement per lane. For example, if the peak 15 min volume is 250 vph, and it is a single left turn lane with a 150 sec cycle, the amount of green time needed will be 2(10.4 cars per cycle) + 3 sec start up time, or 23.8 sec of green time. So if we had a 3 sec yellow and a 2 sec all-red for the left turn, a good tight split would be 29 secs. The 10.4 cars per cycle came from 250 vph/24 cycles per hour for a 150 sec cycle length (3600 sec/150 sec per cycle).
- ✓ If the left turn was a double left in this example, the amount of green time needed would be 2(10.4 cars per cycle) divided by 2 because of two left turn lanes + 3 sec startup time. So the double left would need 13.4 sec of green or a good tight split of 18 to 19 secs.
- ✓ It's important to cut splits for all movements and for all timing plans because Synchro gives too much green time to the cross street and left turns at under-capacity intersections. If we used Synchro's splits, we would have too many stragglers when we just want to clear the queue that's there and get back to the mainline. By cutting the splits, it opens up possibilities for better progression in both directions so that's why it's the crucial key step before looking at progression.
- ✓ We are open to having a little more cushion on the splits (extra 5 sec or so) for the offpeak plans that will be running on weekends since those peak 15 minute counts are from Mon-Fri at Noon which may be different than periodic surges in the evening or weekends.
- ✓ Once you cut the splits, you should then have Synchro reoptimize the offsets and lead/lag sequence while keeping the splits fixed. Synchro then may find a better option for two-way progression with the tighter splits.

8. Protected Lefts Should Typically Be Lead-Lag on Cross Street

- We have found some efficiency gains by letting one-side go and then the other side go so opposing left turns don't have to worry about running into each other. This also reduces frustration for protected lefts who would see an adjacent red instead of an adjacent green ball while they are waiting on the red arrow. Typically, we run the lowest volume side first so the heavier side can use the extra green time with the Floating Force Off set to No. However, this isn't necessary if

progression works better with the heavier side going first. Also, you may want to consider having leading lefts if the cross street throughs are both heavy with light left turns so that the throughs can take advantage of extra time for the cross street.

9. Time Space Diagram

- Have Synchro files set up with 70th percentile for viewing Time-Space Diagram to best represent typical traffic flow. The scale in the Time-Space Diagram Options should be set to 48 seconds per inch for Time and 1000 ft per inch for distance to best view flows when fine-tuning.

- The final step we want you to do is to see if you can improve Synchro's offsets and lead/lag sequence through manual adjustment of the Time Space Diagram. It is nice to have the back end of the platoons lined up from one intersection to the next if possible.

10. Sim Traffic Analysis

- Use UTDF to run actual 15 minute volumes (not peak 15 min * 4) when running Sim Traffic for realistic runs

11. Things to Consider when Choosing Best Timing Plan

- ✓ Good progression on Syncho Time-Space Diagram is most important
- ✓ Use SimTraffic in peak periods (no need to run SimTraffic in undercapacity offpeak periods) to analyze:
  1) Storage Issues
  2) Interaction between close intersections
  3) Overcapacity roads where cumulative shockwaves may not be evident in the Synchro Time Space Diagram
- ✓ Look at Delay, Stops, and Travel Time in Synchro and SimTraffic to weigh the best timing plans for close calls. SimTraffic should get greater weight.

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Metro Checklist for Synchro Files

MnDOT Metro - Procedure For Initiating "Twice Per Cycle Left Turns"

VER 5/27/07

ASC2, ASC2S CONTROLLER PROGRAMMING and ARIES DATA BASE ENTRY

Main Menu, Controller, Configuration, Sequence

Program Twice Per Cycle Left Turn (TPCLT) phases in the controller sequence priority ring and barrier locations. Example; for a typical mainline situation move phases 9 & 11 to the same side of the barrier that phases 1,2,5,6 are in. Place phase 9 after phases 1 & 2. Place phase 11 after phases 5 & 6. Zeroing out the current barrier and phase arrangement first, will make it easier to program the new configuration. It is allowable to use only one left turn phase as a TPCLT phase. Example; on a ramp where there is only one left turn movement.

NOTE: This step must be done on the bench or in the field while the signal is in "Police Panel Flash". In the field, put the signal to flash. Put the "Continuous Time Override" switch in the over ride position! After moving the barriers and phases to the new configuration, press the status display button and follow the initialization instructions as prompted by the controller. It will take about 30 sec or less for the change to take affect in the controller. During that time do not push any buttons until you are prompted to do so. The ASC controller may automatically do a "Warm Start". It might go to the data menu. At that point you may continue the rest of the programming. The remaining steps should be done in the field for safety reasons and verification of correct signal operation. Return the "Continuous Time Override" switch to the normal position! Take the signal out of flash AFTER you have completed the following steps.

Additional programming steps:

Main Menu, Controller, Configuration, Phases in use

Select phases 9 & 11 for TPCLT use by selecting "yes". Label the new phases the same as phases 1(9) and 5(11).

Main Menu, Controller, By-Phase Timing Data, Min Timing

Duplicate the minimum timing data of the left turn phases to be twice cycled in the new phases 9 & 11. Phase 9 will duplicate phase 1 and Phase 11 will duplicate phase 5.

Main Menu, Controller, By-Phase Timing Data, Extension/Max

Duplicate the extension and max timing data of the left turn phases to be twice cycled in the new phases 9 & 11. Phase 9 will duplicate phase 1 and Phase 11 will duplicate phase 5.

Main Menu, Controller, By-Phase Timing Data, Clearance

Duplicate the clearance timing data of the left turn phases to be twice cycled in the new phases 9 & 11. Phase 9 will duplicate phase 1 and Phase 11 will duplicate phase 5.

Main Menu, Controller, Vehicle/Ped Phase as Overlap, Vehicle

Reading the vehicle phases across the top of the data page, put a check in the box of the phases 9 & 11 to the right of phases 1 & 5 running up and down on the left side of the data page. Typically your new check marks will be <u>above</u> the diagonal line of default checks already on the data page. **NOTE: This step must be done in the field. This change will not be downloaded with the other data.**

Main Menu, Controller, Recall Data, Dimming, Recall

<u>Do not</u> put a check mark in the locking Memory of the new phase 9 & 11. (At this time there is an issue of the left turn "Twice Cycling" when there may be no demand for either a leading or lagging left turn. Not selecting the locking memory option for phases 9 & 11 eliminates unneeded lagging turns, but un-needed leading turns can still occur).

Main Menu, Controller, Detector Phase Assignment

Put checks in the boxes on the data page that will assign the detectors of the original left turn phases 1 & 5 to the new TPCLT phases 9 & 11, respectively.

Main Menu, Controller, Coordination Patterns, Select Coordinator Pattern

Go to the coord patterns that will use the TPCLT function. Reduce the mainline left turn split times of phases 1 & 5. Give the time to the new phases 9 & 11. Be sure your new split times for the original left turn and new left turn phases is long enough to accommodate the basic minimum timing, including the clearances. Be sure the final total split times still add up to the cycle length. **NOTE**: **Do not use the "Alternate Sequence" selections for the original left turn phases (1 or 5) when the TPCLT phases are active in the coord patterns.**

Main Menu, Controller, Coordination Patterns, Select Coordinator Pattern, Phase Omit

Place a check mark in the appropriate box to "allow" or "omit" the twice per cycle phase 9 & 11.

Each coord pattern will need to be updated accordingly as the TPCLT phases will **always** be available, omitted, or active by the coord patterns selected. During a "FREE" coord pattern, the TPCLT phases will be active and using front page timing.

Main Menu, Controller, TOD Program Steps

To omit any TPCLT operation during any "FREE" steps in the coordination plans, you must create a TOD plan that uses "Phase Omits" for those "FREE" coord steps. The phases being omitted during "FREE" will be those created for the TPCLT phases, 9 or 11, and not needed in "FREE" mode.