Utah Department of Transportation

Automated Traffic Signal Performance Measures Methods and Assumptions Manual

Prepared for:

Utah Department of Transportation
4501 Constitution Blvd.,
Taylorsville, UT 84129

Prepared by:

Avenue Consultants
6605 S Redwood Rd,
Taylorsville, UT, 84123

**Special thanks to the
Pennsylvania Department of Transportation**

12/5/2022

Document Control Panel	
File Name:	ATSPM Method & Assumptions.docx
Version No.:	1.0
Created By:	
Date of First Submission:	
Updated By:	
Client Comments Received:	

Revision History Control Panel		
CREATED BY:	David Bassett, Avenue	
	Nuzhat Azra, Avenue	
	Camille Lunt, Avenue	
REVIEWED BY:	Shawn Larson, Avenue	
TECHNICAL REVIEW:	Mark Taylor, UDOT	
	Steve Gault, PennDOT	
MODIFIED BY:		
COMPLETED BY:		

CONTENTS

LIST OF EXHIBITS

INTRODUCTION

As the number and complexity of traffic signals continue to grow it has become critically important to evaluate the performance of traffic signals quickly and easily. Numerous options are available to help evaluate traffic signal performance, many of which use high resolution data collected and provided by the traffic signal controllers. This document is designed as a companion to the existing manuals and websites to define the methodology and assumptions used to created measures and graphic in the opensource code used in the Automated Traffic Signal Performance Measures (ATSPM) website.

The document is organized by measure and provides a list of the data required and the algorithms used for each measure. A brief description of the analysis methods is provided for each measure. For clarity each process to develop the measure is then documented in step format. The measure algorithms are based on the analysis time-period for each measure and so the period may represent different timeframes for each measure (i.e., bin, hour, cycle, plan in effect etc.). In addition to the time periods many of the measures are analyzed by phase and/or cycle and then aggregated to a higher level. This document uses equations with defined parameters and variables to help convey those specifics.

1. APPROACH VOLUME

OVERVIEW

Volume data can be useful when programming signal timing values or troubleshooting detection issues and is also often collected for planning purposes. This measure reports the number of vehicles observed on an approach (*1*). The number of vehicles is normalized to a flow rate (in vehicles per hour). The data may be aggregated into custom-sized bins, with 15 minutes being the default.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the approach volume measure. The data are listed in Exhibit 1.

Exhibit 1 Required Input Data for Approach Volume Measure

Required Data and Units	Source Data	Notes
Detector Activation*	EC 82 – Detector On	
Detector Channel	Event Parameter Field [DetChannel] in Detector Table	
Detector setback, ft	Field [DistanceFromStopBar] in Detector Table	Measured from leading edge of detector to stop bar
Approach speed, mph	Field [MPH] in Approaches Table	Speed limit of roadway
Approach ID	Field [ApproachID] in Approaches Table	
Latency correction, s	Field [LatencyCorrection] in Detector Table	

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

The approach volumes can be determined using either lane-by-lane count detectors at the stop bar or advanced count detectors upstream of the intersection. If both sensor types are present at an approach, the approach volume is computed for each sensor group and two sets of results are displayed (one for each sensor group). Opposing directions (NB/SB and EB/WB) are calculated and presented together to identify the directional distribution. The framework for computing approach volume is as follows:

1. Identify and adjust vehicle activations
2. Calculate volumes
3. Determine the peak hour and peak hour volume
4. Calculate peak hour factor, K factor, and D factor

COMPUTATIONAL STEPS

Step 1: Identify and Adjust Vehicle Activations

During this step, the vehicle actuation events are identified in the high-resolution event log. The event log is queried to find the events where the Event Code is 82 and the signal ID, timestamps, and Event Parameter (EP) of each record in the query are identified. Timestamps for vehicle actuations may need to be adjusted using Equation 1 to standardize vehicle arrivals based on detector location or possible latency differences. The correction is calculated as follows:

$$t_{adjva,v} = t_{va,v} + \frac{d}{s \times 1.467} - lc$$

Equation 1

Where:

t_{adjva} = adjusted time stamp of arrival time

v = individual vehicle as defined by detector on event (EC 82)

t_{va} = time stamp of arrival time (EC 82)

d = stated distance to stop bar

s = stated speed for the approach

lc = latency correction, based on system latency factors

The adjusted vehicle arrival time ($t_{adjva,v}$) is used for all the following computational steps.

Step 2: Calculate Volumes

In this step the volumes for a given approach are calculated. The list of vehicle arrivals is queried to find the events within the analysis period. Using support tables, the detector channels (which are the Event Parameters in the queried high-resolution data as identified in Step 1) are associated with the approach using the field Approach ID. The total number of vehicle arrivals for the approach are summed over the analysis period of interest to determine the approach volume.

$$V_A = \sum_i |VA_i|_0^t$$

Equation 2

Where:

V = approach volume

A = approach at an intersection

VA = vehicle actuations

i = individual detector channel from approach A, derived from event parameter of detector on events (EC 82)

t = analysis period

Volumes from two opposing directions (e.g., northbound, and southbound) are added together for each analysis period to determine the total (bi-directional) volume.

Step 3: Determine Peak Hour and Peak Hour Volume

The peak hour is determined within the user-specified datetime range based on the bin size. The volumes for each bin are the summed for progressive 60-minute periods to be used to determine the peak hour. The 60-minute aggregation of bins with the highest volume for each approach identified as the peak hour for that approach. Similarly, the 60-minute aggregation of bins for both approaches with the highest total volume is identified as the overall peak hour for the approach pair. The volumes for these identified periods are determined to be the Peak Hour Volume.

Step 4: Calculate Peak Hour Factor (PHF), Peak Hour K Factor, and Peak Hour D Factor

The peak hour factor is defined as the peak hour volume (in vph) divided by the peak 15-minute flow rate (in vph).

Equation 3

$$PHF = \frac{V_{app,PH}}{4 \times V_{app,P15}}$$

Where:

PHF = peak hour factor for approach A

V_A = volume (in vph) of approach A

PH = peak hour for approach A

P_{15} = peak 15-minute period within the peak hour

4 = bin size multiplier for 15-minute periods

The peak hour D factor is calculated for each direction for the peak hour by dividing the peak hour directional volume by the total bi-direction peak hour volume. The D factor is rounded to the thousandths place.

Equation 4

$$D_a = \frac{PHV_a}{V_{A,a} + V_{A,b}}$$

Where:

D = peak hour D factor for direction a

PHV = peak hour volume

a, b = denotes directionality, where a is the direction for which D is being calculated and b is the opposite direction

V_A = approach peak hour volume (Equation 2)

The peak hour K factor is calculated by taking the ratio of bi-directional peak hour volume to the total bi-directional traffic for the user-defined datetime range. The user-defined range typically is a 24-hour period but can be shorter or longer based on the user's needs. Similar values are calculated for each approach. The K factor is rounded to the thousandths place.

Equation 5

$$K_a = \frac{HV_{a,PH_a} + HV_{b,PH_a}}{V_{A,a} + V_{A,b}}$$

Where:

HV = hourly volume for an approach for a peak hour of a given direction

PH = peak hour for direction a or b

a, b = denotes directionality

V_A = approach volume (Equation 2)

EXAMPLE

An example approach volume measures diagram is shown in Exhibit 2. The data for approach volumes is displayed in both graph and table form. As shown in the exhibit, the graph shows the two opposing volumes throughout the analysis period along with the D-factor for each bin. The graph also indicates the type of detection used to collect the data. The table is a breakdown of total of the opposing approaches and each approach individual including, volumes, PHF, D-Factor, and K-Factor all for the Peak Hour. Note the K-Factor is based on the bi-directional peak hour.

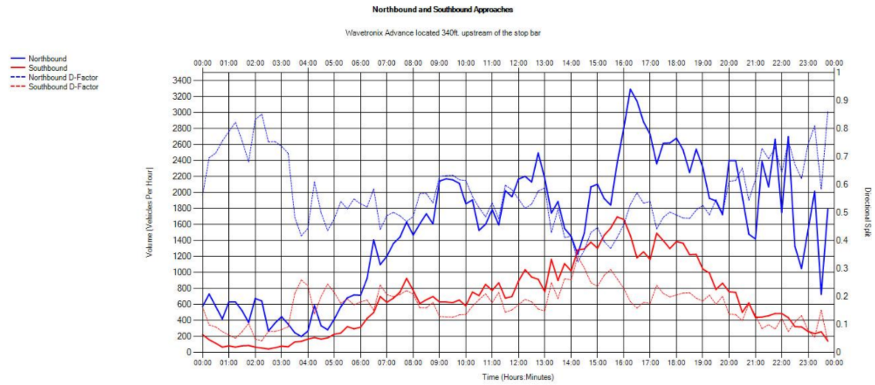


Exhibit 2 Example Approach Volume Diagram

Metric	Value
Peak Hour	5:15 PM - 6:15 PM
K Factor	0.065
Peak Hour Volume	3228
Peak Hour Factor	0.871
Total Volume	49661
-	-
Northbound Peak Hour	9:15 PM - 10:15 PM
Northbound Peak Hour D Factor	0.78
Northbound Peak Hour K Factor	0.06
Northbound Peak Hour Volume	2340
Northbound Peak Hour Factor	0.927
Northbound Total Volume	30239
-	-
Southbound Peak Hour	4:45 PM - 5:45 PM
Southbound Peak Hour D Factor	0.5
Southbound Peak Hour K Factor	0.063
Southbound Peak Hour Volume	1574
Southbound Peak Hour Factor	0.964
Southbound Total Volume	19422

2. PHASE TERMINATION

OVERVIEW

Actuated phases terminate either because there is a gap in traffic or because the phase has reached its maximum programmed time. This measure reports the reason that individual phases terminated (i.e., a gap out, max out, force off, or skip). This measure can be useful for identifying phases that are consistently using all the allocated green time, either due to servicing high demands or due to faulty calls (*1*).

REQUIRED DATA AND SOURCES

Exhibit 3 describes the input data needed for the phase termination measure.

Exhibit 3 Required Input Data for Phase Termination Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 4 – Phase Gap Out EC 5 – Phase Max Out EC 6 – Phase Force Off EC 7 – Phase Green Termination	Must be provided If green termination time is not available, the timestamp for the phase termination event will be used
Phase	Event Parameter	Must be provided
Phases with pedestrian service*	EC 23 – Pedestrian Begin Don't Walk	For phases with pedestrian service

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

Traffic signal controllers may terminate a phase which is currently green to serve another phase (*4, 5*) if there is a serviceable conflicting call. A signal controller will then report a gap out, max out, or force off event for the terminated phase or in the absence of those as unknown termination can be calculated. The calculation framework for phase terminations is as follows:

1. Determine phase termination time
2. Determine unknown phase termination
3. Identify pedestrian events

COMPUTATIONAL STEPS

Step 1: Determine Phase Termination Time

Use caution with the Phase Gap Out event, as some controller software incorrectly applied this whenever the gap timer reached zero, which may have occurred multiple times while the phase was green (such as if an active phase in another ring was still serving demand). This situation was addressed by adding Event Code 13 in the 2020 edition of the Enumerations.

During this step, the phase termination events (EC 4, 5, or 6) and timestamp associated with each phase termination are determined. The timestamp for the event may vary based on the controller type to when the event is programmed to be reported. Some controller software records the phase termination event at the same time as the phase termination occurs (change from green to yellow). Other controller software may record the phase termination event prior to the phase termination. Following are examples of situations when the phase termination event timestamp may not match the phase termination timestamp:

- Simultaneous gap is not enabled, and the termination decision is reached for a phase in one ring while a phase in another ring is still servicing demand, or
- Phases in different rings have different maximum times set.

To ensure the correct timestamp is located for each phase termination, the timestamps of the phase termination events within the same cycle are compared to locate the first termination event. In the case where multiple termination events are logged in the same cycle the timestamp of the first occurrence is considered the time of termination. To determine this, for each phase termination event type (EC 4, 5, or 6), find the same event parameter as the subject phase.

$$t_{tt,p} = min(t_{te,p})$$

Equation 6

where $t_{tt,p} \geq t_{te,p}$ and

t_{tt} = phase termination time

p = phase, derived from event parameter of cycle events

te = phase termination events (EC 4, 5, and 6)

t_{te} = time stamp for phase termination events (EC 4, 5, or 6)

Step 2: Determine Unknown Phase Termination

During this step, cycles with an unknown phase termination type are determined.

If the controller software does not record EC 4, 5, or 6 the phase type unknown can be determined by reviewing the cycle sequence of Phase Green Termination (EC 7) and the other termination events (EC 4, 5, or 6).

The methodology in this step could be used to add Event Code 14 to the controller event log in a database to simplify future analysis.

An unknown phase termination is identified whenever sequential Phase Green Termination events (EC 7) occur without termination event (EC 4, 5, or 6) occurring in between. In these cases, the absence of an event code 4, 5, or 6 prohibited the identification of the termination type, and is assigned the type "Unknown" and logged using the timestamp of the initial EC 7 in the check.

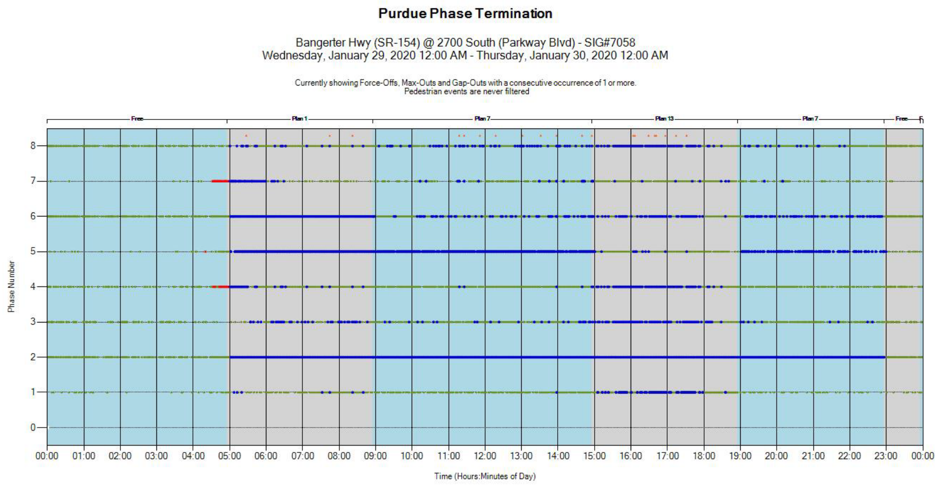
Step 3: Identify Pedestrian Events

In this step, times when the pedestrian phase is on are determined. For each cycle that a Pedestrian Begin Walk event (EC 21) is followed by a Pedestrian Begin Solid Don't Walk event (EC 23) within the same cycle, the timestamp of EC 21 is recorded.

EXAMPLE

An example phase termination diagram is shown in Exhibit 4, which represents a controller using eight phases (1-8). Phase 8 also has pedestrian activity, represented by orange dots above the phase termination events.

Exhibit 4 Example Phase Termination Diagram



3. SPLIT MONITOR

OVERVIEW

The split monitor measure is used to report detailed information about the performance of an individual phase. Using high-resolution data, it combines a plot of phase duration with several other pieces of information– termination type, pedestrian phase service, and programmed splits. This measure is useful for assessing whether signal timing parameters have been programmed correctly, how much of the programmed split is being used, and whether signal timing adjustments had an impact. The pattern change information can also be used to infer events such as interruption of a pattern by preemption or priority control (*1*).

REQUIRED DATA AND SOURCES

Exhibit 5 describes the input data needed for the split monitor measure.

Exhibit 5 Required Input Data for Split Monitor Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 1 – Phase Begin Green EC 4 – Phase Gap Out EC 5 – Phase Max Out EC 6 – Phase Force Off EC 7 – Phase Green Termination EC 8 – Phase Begin Yellow Change EC 9 – Phase End Yellow Change	Must be provided If EC 4, EC 5, and EC 6 are not available, then EC 7, EC 8, or EC 9 will be used
Pedestrian Cycle*	EC 21 – Pedestrian Begin Walk EC 23 – Pedestrian Begin Solid Don't Walk	
Programmed Splits*	EC 134 thru 149 – Split Change	
Phase	Event Parameter	Must be provided

Notes: EC = Event Code
*All data for EC code are stored in controlled event log table

OVERVIEW OF THE METHODOLOGY

This measure identifies the reason and time after the begin of cycle for ending each green phase. This is accomplished by reviewing the controller-logged event codes for each cycle. This measure also calculates the percent of skips, percent gap outs, percent max outs, and percent force offs in addition to determining the average split, the percentile splits, and the timing plans used. The computational framework is as follows, repeated for each phase at the intersection:

1. Determine phase termination time
2. Determine unknown phase termination
3. Identify pedestrian events
4. Calculate percent skips
5. Calculate percent gap outs
6. Calculate percent max outs
7. Calculate percent force offs
8. Calculate average split
9. Determine percentile splits
10. Determine programmed splits

COMPUTATIONAL STEPS

Step 1: Determine Phase Termination Time

Use caution with the Phase Gap Out event, as some controller software incorrectly applied this whenever the gap timer reached zero, which may have occurred multiple times while the phase was green (such as if an active phase in another ring was still serving demand). This situation was addressed by adding Event Code 13 in the 2020 edition of the Enumerations.

During this step, the phase termination events (EC 4, 5, or 6) and timestamp associated with each phase termination are determined. The timestamp for the event may vary based on the controller type to when the event is programmed to be reported. Some controller software records the phase termination event at the same time as the phase termination occurs (change from green to yellow). Other controller software may record the phase termination event prior to the phase termination. Following are examples of situations when the phase termination event timestamp may not match the phase termination timestamp:

- Simultaneous gap is not enabled, and the termination decision is reached for a phase in one ring while a phase in another ring is still servicing demand, or
- Phases in different rings have different maximum times set.

To ensure the correct timestamp is located for each phase termination, the timestamps of the phase termination events within the same cycle are compared to locate the first termination event. In the case where multiple termination events are logged in the same cycle the timestamp of the first occurrence is considered the time of termination. To determine this, for each phase termination event type (EC 4, 5, or 6), find the same event parameter as the subject phase.

Equation 7

$$t_{tt,p} = min\left(t_{te,p}\right)$$

where $t_{tt,p} \geq t_{te,p}$ and

t_{tt} = phase termination time

p = phase, derived from event parameter of cycle events

te = phase termination events (EC 4, 5, and 6)

t_{te} = time stamp for phase termination events (EC 4, 5, or 6)

Step 2: Determine Unknown Phase Termination

During this step, cycles with an unknown phase termination type are determined.

The methodology in this step could be used to add Event Code 14 to the controller event log in a database to simplify future analysis.

If the controller software does not record EC 4, 5, or 6 the phase type unknown can be determined by reviewing the cycle sequence of Phase Green Termination (EC 7) and the other termination events (EC 4, 5, or 6).

An unknown phase termination is identified whenever sequential Phase Green Termination events (EC 7) occur without termination event (EC 4, 5, or 6) occurring in between. In these cases, the absence of an event code 4, 5, or 6 prohibited the identification of the termination type, and is assigned the type "Unknown" and logged using the timestamp of the initial EC 7 in the check.

Step 3: Identify Pedestrian Events

In this step, times when the pedestrian phase is on are determined. For each cycle that a Pedestrian Begin Walk event (EC 21) is followed by a Pedestrian Begin Solid Don't Walk event (EC 23) within the same cycle, then two values are recorded: the timestamp of EC 21 and the number of seconds between the timestamps for EC 23 and EC 21.

Step 4: Calculate Percent Skips

This step calculates the percent of cycles for each phase that the phase was skipped by the controller. The percent of cycles that skipped the phase is calculated as:

$$P_{sk} = \frac{C_{max} - C_p}{C_{max}}$$

Equation 8

Where:

P_{sk} = percent skips (in decimal form)

p = phase, derived from event parameter of cycle events

C_{max} = maximum number of cycles occurring for all phases at the intersection

C_p = number of cycles during which phase p was called within the analysis period

Step 5: Calculate Percent Gap Outs

This step calculates the percent of cycles for each phase that terminated from a gap out. The number of cycles ending in a gap out is calculated as follows:

$$GO_p = \left|TE_{4,p}\right|_{t=0}^{t=t}$$

Equation 9

Where:

GO = number of gap outs

TE_4 = termination event code 4 occurring

t = analysis period t

p = phase, derived from event parameter of cycle events

The percent of cycles terminating from a gap out is calculated as:

$$P_{go} = \frac{GO_p}{C_{max}}$$

Equation 10

Where:

P_{go} = percent gap outs (in decimal form)

GO_p = number of gap outs for phase p (Equation 9)

C_{max} = maximum number of cycles within the analysis period occurring for all phases at the intersection

Step 6: Calculate Percent Max Outs

This step calculates the percent of cycles for each phase that terminated from a max out during free operation. The number of cycles ending in a max out is calculated as follows:

$$MO_p = |TE_5|_{t=0}^{t=t}$$

Equation 11

Where:

MO = number of max outs

TE_5 = termination event code 5

t = analysis period t

p = phase, derived from event parameter of cycle events

The percent of cycles terminating from a max out is calculated as:

Equation 12

$$P_{mo,p} = \frac{MO_p}{C_{max}}$$

Where:

P_{mo} = percent max outs (in decimal form)

p = phase, derived from event parameter of cycle events

MO_p = number of max outs (Equation 11)

C_{max} = maximum number of cycles within the analysis period occurring for all phases at the intersection

Step 7: Calculate Percent Force Offs

This step calculates the percent of cycles for each phase that terminated from a force off when a coordinated pattern is in use. The number of cycles ending in a force off is calculated as follows:

Equation 13

$$FO_p = |TE_6|_{t=0}^{t=t}$$

Where:

FO = number of force offs

TE_6 = termination event code 6

t = analysis period t

p = phase, derived from event parameter of cycle events

The percent of cycles terminating from a force off is calculated as:

Equation 14

$$P_{fo} = \frac{FO_p}{C_{max}}$$

Where:

P_{fo} = percent force offs (in decimal form)

p = phase, derived from event parameter of cycle events

FO_p = number of force offs (Equation 14)

C_{max} = maximum number of cycles within the analysis period occurring for all phases at the intersection

Step 8: Calculate Average Split

In this step, the split durations for each phase are calculated by subtracting the time between the end of red clearance interval (EC 11) and the previous start of green interval (EC 1). The split durations are calculated as:

Equation 15

$$T_{Cp} = t_{erc,cp-}\ t_{g,cp}$$

Where:

T = split duration (in seconds)

t_g = timestamp for begin of green interval (event code 1) during cycle C

t_{erc} = timestamp for end of red clearance interval (event code 11) during cycle C

C = individual cycle

p = phase, derived from event parameter of cycle events

Average splits for a phase are calculated using the following equation:

$$S_{avg,p} = \frac{\sum_{t=0}^{t=t} T_{cp}}{\left|T_{cp}\right|_{t=0}^{t=t}}$$

Equation 16

Where:

S_{avg} = average split duration (in seconds)

p = phase, derived from event parameter of cycle events

t = analysis period t

T = split duration (in seconds) (Equation 15)

C = individual cycle

Step 9: Determine Percentile Splits

In this step, the split durations for each phase are sorted from smallest to largest. The X^{th} percentile split is then determined based on the sorted list. If the user-specified percentile (in decimal form) multiplied by the number of cycles in the analysis period results in a whole number, then the X^{th} percentile split duration is the N^{th} duration in the ordered list, using:

$$If\ |SD| \times X\ \%\ 1 = 0,$$
$$SD_{xth} = SD_{Nth}$$
$$N = |SD|_o{}^t \times X - 1$$

Equation 17

Where:

SD = split duration (in seconds)

X = analysis percentile (in decimal form)

N = rank of a split duration in the ordered list

If the user-specified percentile multiplied by the number of cycles in the analysis period does not result in a whole number, then the percentile index is found using:

$$PI = (|SD| \times X - 0.5)$$

Equation 18

Where:

PI = percentile index

SD = split duration

X = analysis percentile in decimal form

The percentile index is rounded to the nearest whole number. The rounded percentile index is then used in the following equation to determine the X[th] percentile split duration.

Equation 19

$$SD_X = \left(\left(SD_{PI_i} - SD_{PI_{i-1}}\right) * r\right) + D_{PI_i}$$

Where:

SD_X = the X[th] percentile split duration

D_{PI_i} = split duration corresponding to [percentile index - 1] (note that a previous step sorted the split durations in ordered from smallest to largest)

$D_{PI_{i-1}}$ = split duration corresponding to [percentile index]

r = the remainder of ($|SE| \times X$) ÷ 1

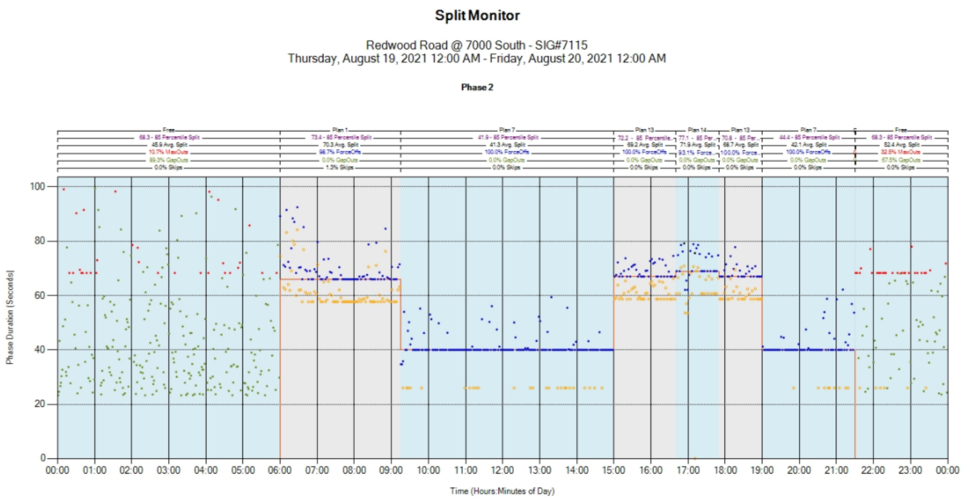
Step 10: Determine Programmed Splits

In this step, the program uses the event codes (between EC 134 and EC 149) to step through each phase and records the event parameter as split duration. This split duration is the programmed split for different plans.

EXAMPLE

An example of the Split Monitor chart is shown in Exhibit 6. The chart shows programmed split with an orange line, the termination type and split duration with colored dots, and the pedestrian activity with yellow circles for each cycle. The chart also displays the calculated statistics (termination type percentages, average split duration, and percentile split durations) above the chart.

Exhibit 6 Example Split Monitor Diagram



4. PURDUE SPLIT FAILURE

OVERVIEW

A "split failure" is an occurrence when one or more vehicles in the queue at the start of green cannot proceed through a signalized intersection before the end of the phase. A phase that has multiple consecutive split failures is very likely to have an operational problem that can potentially be fixed by increasing the split (or the max time under fully actuated control) or adjusting detection settings (e.g. passage time). (*1*).

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the Purdue Split Failure measure. The data are listed in Exhibit 7.

Exhibit 7 Required Input Data for Purdue Split Failure Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 1 – Phase Begin Green EC 4 – Phase Gap Out EC 5 – Phase Max Out EC 6 – Phase Force Off EC 8 – Phase Begin Yellow Change EC 9 – Phase End Yellow Change	Must be Provided
Detector Activation*	EC 81 – Detector Off EC 82 – Detector On	
Detector Channel	Field [DetChannel] in Detector Table	Must be provided and is associated with each required EC
Phase	Event Parameter	Must be provided

Notes: EC = Event Code
*All data for EC code are stored in controlled event log table

OVERVIEW OF THE METHODOLOGY

This measure identifies cycles where there are unserved vehicles. This is accomplished using the occupancy ratios for both the green time (which includes the green interval only) and first five seconds of the red interval. The portion of the red interval used is based on methods from previous research. *(5).* The measure determines the Green Time Occupancy Ratio (GOR), Red Time Occupancy Ratio (ROR), whether the cycle experienced a failure or not, percent of failing cycles, and whether the green interval terminated as a Gap Out. The computational framework is as follows:

1. Identify cycle events
2. Identify termination type
3. Calculate detector activation duration
4. Identify cycle state intervals
5. Calculate green time and red analysis time
6. Calculate red and green occupancy time
7. Calculate GOR and ROR
8. Determine if cycle split failed
9. Calculate percent of cycles with failure

COMPUTATIONAL STEPS

Step 1: Identify Cycle Events

During this step, cycle events (EC 1, 8, and 9) and their timestamps are identified by querying the event log. The cycle events needed for the Purdue Split Failure measure are end of yellow clearance interval (EC 9), the start of green interval (EC 1), and the start of yellow clearance interval (EC 8). Within each analysis period, the cycle events need to follow sequence of EC 1, EC 8, EC 9, and EC 1. Otherwise, the data is not included in further calculations.

Step 2: Determine Phase Termination Type

During this step, the event log is queried to identify the termination events (Event Codes 4, 5, and 6). The query uses the timestamp from the first and second EC 1 determined in Step 1 to find the termination events for each given phase cycle. To ensure the correct type is identified for each phase cycle termination, the timestamps of the phase termination events within the same cycle are compared to locate the first termination event. In the case where multiple termination events are logged in the same cycle, the timestamp of the first occurrence is considered the time of termination. To determine this, the same event parameter as the subject phase must be found for the phase termination event.

$$t_{tt,p} = min(t_{te,p})$$

Equation 20

where $t_{tt,p} \geq t_{te,p}$ and

t_{tt} = phase termination time

p = phase, derived from event parameter of cycle events

te = phase termination events (EC 4, 5, and 6)

t_{te} = time stamp for phase termination events (EC 4, 5, or 6)

Step 3: Calculate Detector Activation Duration

During this step, the event log is queried to find all the EC 81 and EC 82 events within the analysis period where the Event Parameters match the detector channel for the given phase and movement where the detector is type 6 (Stop Bar Presence). Each EC 82 is paired with next EC 81 based on timestamp. If multiple stop-bar detectors are used for a given phase and movement type, the detector actuations are combined into a single detection activation by stepping through the events to find when it transitions from at least one detector is active to when no detectors are active. For each detector activation (combination of detector on and detector off timestamps) the duration of activation is calculated as follows

$$DA_{jm} = Doff_{j,m} - Don_{j,m}$$

Equation 21

where $Doff_{i,m} \geq Don_{i,m}$ and

DA = duration of time (in seconds) during which the detector is active

j = a set of EC 82 (detector on) and EC 81 (detector off) after combining the detector events

m = lane group or movement

$Doff$ = Detector off event (EC 81)

Don = Detector on event (EC 82)

Step 4: Identify Cycle State Intervals

For the Split Fail measure, the timestamp for the start of the green interval (EC 1) and the time stamp for the end of the yellow clearance interval (EC 9) need to be identified for each set of cycle events. Using the data identified in Step 1, the event codes EC 1, EC 8 and EC 9 are organized by phase and timestamp to create an ordered list of events. The first EC 1 in the list for the given phase is then identified along with the three cycle events that follow. For each EC 1 (i) the sequential events must be:

$i + 1$ = EC 8

$i + 2$ = EC 9

$i + 3$ = EC 1

If the sequence is met, the timestamps are identified and passed on for use in other steps. The timestamps are identified as EC $1_i = t_g$, EC $8_{i+1} = t_y$, EC $9_{i+2} = t_r$, and EC $1_{i+3} = t_e$.

Step 5: Calculate Green Time and Red Analysis Time

For the split failure to be determined, the duration of green time and the analysis portion of red time must be calculated. The green time is defined as the time from start of green interval (EC 1) to the start of yellow clearance interval (EC 8) and will be used in the Green Occupancy Ratio (GOR) calculations. The red analysis time is defined as the portion of red interval (red clearance interval + red interval) that will be used in the Red Occupancy Ratio (ROR) calculations. The red analysis time is identified as the first 5 seconds after the end of the yellow clearance interval (EC 9). See the following equations.

Equation 22

$$GT_{Cp} = t_{y,Cp} - t_{g,Cp}$$

Where:

GT = green interval (in seconds) where signal is green

C = individual cycle

p = phase, derived from event parameter of cycle events

t_g = timestamp for start of green interval (EC 1)

t_y = timestamp for start of yellow clearance interval (EC 8)

Equation 23

$$t_{RT,Cp} = t_{ey,Cp} + t_a$$

Where:

t_{RT} = timestamp for end of red time analysis period

C = individual cycle

p = phase, derived from event parameter of cycle events

t_{ey} = timestamp for end of yellow clearance interval (EC 9)

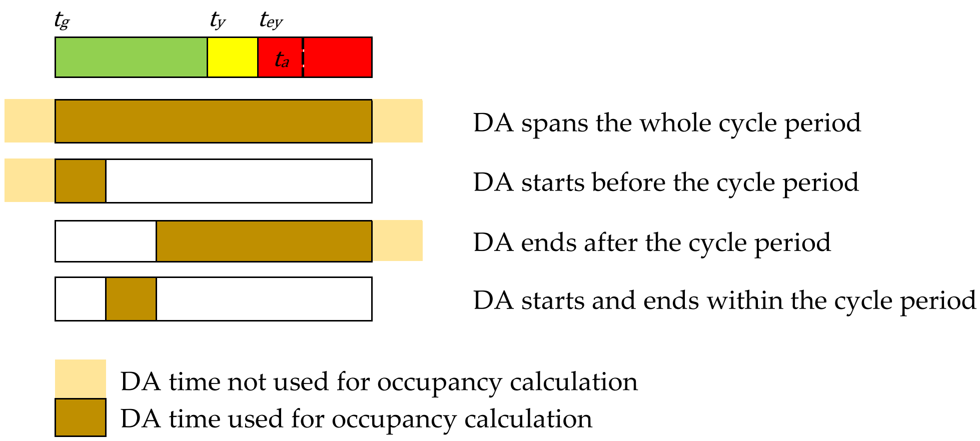
t_a = time in seconds of the red interval to be analyzed (5 seconds is default)

Step 6: Calculate Green and Red Occupancy

The total time that a movement of lane group is occupied is needed to calculate the GOR and ROR. For each of the cycle periods identified in Step 5, the total duration the detectors are active needs to be calculated. Using the detector activation (DA) time periods identified in Step 3 and the green time and red analysis periods boundaries identified in Step 5, the occupancy can be determined. To calculate the green and red occupancy there are four scenarios that need to be evaluated:

1. DA spans the whole cycle periods
2. DA starts before the cycle periods
3. DA ends after the cycle periods
4. DA starts and ends within the cycle periods

Exhibit 8 Occupancy Scenarios



The occupancy for green time and the red analysis time are evaluated separately but follow the same process. Scenario 1 is determined if no start or end of DA fall within the cycle period, and occupancy is set equal to the duration of the cycle period (GT for green time and 5 seconds for red). For Scenario 2, the D*on* timestamp for DA is replaced with timestamp for t_g or t_r and DA is recalculated based on Equation 21. Similarly for Scenario 3, D*off* timestamp for DA is replace with timestamp for t_y or RT and DA is recalculated based on Equation 21. Using the start and end of the cycle period as boundaries, all the DA in Scenario 2-4 are aggregated using the following equation.

Equation 24

$$Occ = \sum_i DA_{dur}$$

Where:

$DA_{Start} \geq CP_{Start}$ & $DA_{End} \leq CP_{End}$

Occ = total time (in seconds) that the detectors are active for a given cycle period

DA_{dur} = detection activation duration for a given lane group or movement

CP = cycle period

Step 7: Calculate GOR and ROR

GOR and ROR are the values used to determine if a cycle for a give phase has experienced failure. They are calculated by dividing the green or red occupancy by the GT or t_a respectively. See equations below

Equation 25

$$GOR_i = (Occ_{g,C}/GT_C) * 100$$

Where:

GOR = green occupancy ratio (in percent)

$Occ_{g,C}$ = total time that the detectors are active for a green analysis period during cycle C

GT = green time during cycle C (Equation 22)

Equation 26

$$ROR_C = (Occ_{r,C}/t_{a,C}) * \ 100$$

Where:

ROR = red occupancy ratio (in percent)

C = individual cycle

Occ_r = total time that the detectors are active for a red analysis period

t_a = time in seconds of the red interval to be analyzed (default is 5 seconds)

Step 8: Determine if Cycle Failed

The Split Failure measure uses ROR and GOR to determine is the cycle has failed or not. For a cycle to meet failure both the GOR and ROR must be greater than 79. If this criterion is met the cycle is flagged as failed and the ROR and GOR are recorded.

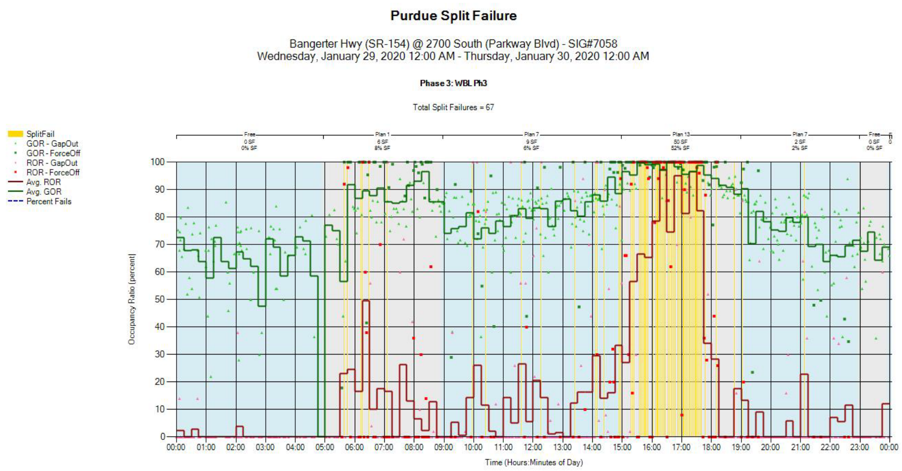
Step 9: Calculate Percent of Cycles with Failure

The Split Failure measure is calculated at the cycle level by phase. Each cycle data is processed through Step 4 – 8. Once all cycles in the analysis period are flagged as failing or not the percentage of cycles during that period is calculated by dividing the number of cycles that failed by the total number of cycles within the analysis period.

EXAMPLE

An example of the Purdue Split Failure chart is shown in Exhibit 9. The charts shows that the GOR and ROR are displayed for each cycle. This points also indicate the phase termination type by the shape of the point. Cycles that have failed are shown as a yellow vertical line while the 15-minute average GOR and ROR are displayed as trend lines across the graph.

Exhibit 9 Example Purdue Split Failure Diagram



5. APPROACH DELAY

OVERVIEW

Vehicle delay is a measure that is commonly modeled by agencies to identify whether intersection operations are acceptable. Using high-resolution data, this measure can be computed directly. For locations with high delay, particularly at uncongested locations, signal timing adjustments can help reduce wait times (*1*). Approach delay is a measure that integrates individual vehicle delay with volume to get an estimated sum of all vehicle delay on an approach.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the approach delay measure. The data are listed in Exhibit 10.

Exhibit 10 Required Input Data for Approach Delay Measure

Required Data and Units	Source Data	Notes
Detector Activation*	EC 82 – Detector On	
Phase Interval Change*	EC 1 – Phase Begin Green EC 9 – Phase End Yellow Change	
Detector setback, ft	Field [DistanceFromStopBar] in Detector Table	Measured from leading edge of detector to stop bar
Approach speed, mph	Field [MPH] in Approaches Table	Speed limit of roadway
Latency correction, s	Field [LatencyCorrection] in Detector Table	Adjustment factor to account for latency between vehicle entering detection zone and the Detector On input being recorded in the controller
Approach ID	Field [ApproachID] in Approaches Table	
Detector Channel	Event Parameter Field [DetChannel] in Detector Table	

Notes: EC = Event Code
*All data for EC code are stored in controlled event log table

OVERVIEW OF THE METHODOLOGY

This measure identifies detection activations that occur during the red interval and determines the individual delay, average delay, and total delay, with delay referencing the amount of time from when a vehicle arrives to when the next green phase begins. This is a simplified approach delay estimate, which does not account for startup delay, deceleration, or queue length that exceeds detection zones. The computational framework is as follows:

1. Identify and adjust detector actuations
2. Identify the beginning of each cycle
3. Identify cycle events
4. Calculate delay values

COMPUTATIONAL STEPS

Step 1: Identify and Adjust Vehicle Activations

During this step, the event log is queried to find the events where the Event Code is 82. The signal ID, timestamps, and Event Parameter (EP) of the EC 82 events are noted. Timestamps for detector on events may need to be adjusted to standardize vehicle arrivals based on detector location or possible latency differences. The correction is calculated as follows:

$$t_{adjva,v} = t_{va,v} + \frac{d}{s \times 1.467} - lc$$

Equation 27

Where:

t_{adjva} = adjusted time stamp of arrival time

v = vehicle v as defined by detector on event (EC 82)

t_{va} = time stamp of arrival time (EC 82)

d = stated distance to stop bar

s = stated speed for the approach

lc = latency correction, based on system latency factors

The adjusted vehicle arrival time ($t_{adjva,v}$) is used for all the following computational steps.

Step 2: Identify the Beginning of Each Cycle

For the Approach Delay measure, the beginning of the cycle is defined as the end of yellow clearance interval (EC 9). The event log is queried to find the events where the Event Code is 9. Each instance of EC 9 is indicated as the first red event of the cycle. The time in the cycle for detector activation (EC 82), start of green interval (EC 1), change to yellow clearance interval (EC 8), and end of yellow clearance interval (EC 9) is calculated in reference to this first red event. The next red event (EC 9) in cycle *j* is considered the phase begin red event, which serves as the end of cycle *j* and the first red event of cycle *j+1*.

Step 3: Identify Cycle Events

During this step, cycle events for Approach Delay measure are identified, and their time stamps are extracted from the high-resolution event log. Cycle events are defined as – end of yellow clearance interval (EC 9), start of green interval (EC 1), and start of yellow clearance interval (EC 8). Within each cycle, first instance of EC 9 (cycle start), EC 1, EC 8 and second instance of EC 9 (end of cycle) need to follow this sequence based on their timestamps. Otherwise, the group of events is not included in further calculations. An adjusted timestamp for EC 82 ($t_{adjva,v}$ in Step 1) can be at any time between the start and end of cycle.

Step 4: Calculate Delay Values

Delay is only calculated for vehicles that arrive on red. Zero delay is assumed for vehicles that arrive on green. Arrivals on red are the vehicle actuations with the adjusted time stamp calculated in Step 1 between Event Code 9 (end of yellow) and Event Code 1 (beginning of green). The delay for each arrival on red is determined from the adjusted detection time to the start of the next green phase such that:

Equation 28

$$d_{v,p} = \sum_{vi} t_{g,C} - t_{adjva,v}$$

Where $t_{g,C} > t_{adjva,v}$ and:

d = delay (in seconds) for all vehicles

v = vehicle v as defined by detector on event (EC 82)

p = phase p, derived from event parameter of cycle events

i = individual detector channel i, derived from event parameter for EC 82

t_g = timestamp for start of green interval (EC 1) during cycle C

$t_{adjva,v}$ = adjusted time stamp of arrival time (Equation 27)

The total approach delay (TD) is determined by summing the individual vehicle delays, within the specified time bins included in the user-defined analysis period.

Equation 29

$$TD_p = \sum_{v} d_{v,p}$$

Where:

TD = total delay (in hours) for all vehicles

$d_{v,p}$ = delay (in seconds) for vehicle v using phase p (Equation 28)

The average delay per vehicle is determined by dividing the TD by the total number of arrivals during the red interval based on adjusted detection events determined in Step 2.

Equation 30

$$d_{avg,p} = \frac{TD_p * 3600}{\sum_i |VA_i|}$$

Where:

d_{avg} = average delay (in seconds)

$d_{v,p}$ = delay for vehicle v for phase p (Equation 28)

VA = vehicle actuations for detector channel i

EXAMPLE

An example approach delay diagram is shown in Exhibit 11. This is an example of one phase approach delay. Each phase will have its own separate graph showcasing the delay per vehicle and delay per hour. The example shows the trends throughout the analysis period as well as calculations of the different delays for each plan and the analysis period. Note the total delay is in hours where the vehicle delay is in seconds.

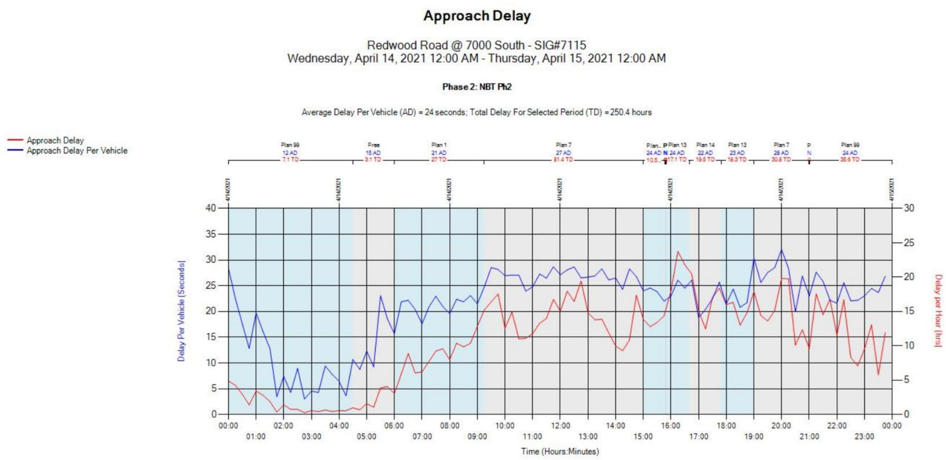


Exhibit 11 Example Approach Delay Diagram

6. PEDESTRIAN DELAY

OVERVIEW

This measure reports the time per cycle between the earliest call for a pedestrian phase (from a button push) until the beginning of the next Walk interval. Although the measure does not necessarily reflect the actual time at which the pedestrian executed the crossing movement, it does reveal the amount of time elapsed between the request and when the controller provided the requested pedestrian interval. In future, passive pedestrian detection might be used to better estimate delay.

A long pedestrian delay may be the result of long cycle lengths, long split times on conflicting phases, or phase order. Transportation Planning professionals may also be interested in pedestrian delay, particularly for a comparison with vehicle and bicycle delay (*1*).

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the pedestrian delay measure. The data are listed in Exhibit 12.

Exhibit 12 Required Input Data for Pedestrian Delay Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 1 – Phase Begin Green EC 8 – Phase Begin Yellow Change EC 9 – Phase End Yellow Change	
Pedestrian Cycle*	EC 21, EC 67 – Pedestrian Begin Walk EC 22, EC 22 – Pedestrian Begin Change Interval	Events listed as typical event code, overlap event code
Phase Control*	EC 45 – Pedestrian Call Registered	Can be used in some controllers
Detector Activation*	EC 90 – Ped Detector On	
Detector Channel	Event Parameter Field [DetChannel] in Detector Table	Must be provided
Approach ID	Field [ApproachID] in Approaches Table	
Pedestrian Detectors	Field [PedestrianDetectos] in Approaches Table	
Phase	Event Parameter	Must be provided and is associated with each required EC

Notes: EC = Event Code
*All data for EC code are stored in controlled event log table

OVERVIEW OF THE METHODOLOGY

Pedestrian delay is determined by finding the time between the first pedestrian actuation event in a cycle for a specific phase and when the corresponding walk event for that phase begins. The calculation framework for pedestrian delay is:

1. Identify the start of the called phase
2. Calculate pedestrian delay for each call
3. Determine total pedestrian actuations, minimum delay, maximum delay, and average delay

COMPUTATIONAL STEPS

Step 1: Identify the Pedestrian Events

During this step, the event log is queried to find the start and end of the pedestrian phases (event code 21 and 22) as well as the pedestrian detector on event (event code 90) and Pedestrian Call Registered (EC 45) for each phase individually.

Step 2: Identify Vehicle Cycle Events and Cycle Length

During this step, cycle events (EC 1, 8, and 9) and their timestamps are identified by querying the event log. The cycle events needed for further calculation are end of yellow clearance interval (EC 9), the start of green interval (EC 1), and the start of yellow clearance interval (EC 8). A valid cycle consists of first instance of EC 9 (cycle start), EC 1, EC 8, and second instance of EC 9 (cycle end), in that sequence. Any cycle without this sequence is excluded from further analysis. Within an analysis period, the number of valid cycles is recorded and used for ped recall analysis (Step 6).

Cycle length is calculated for each valid cycle such that:

$$CL_{pC} = t_{ey,pC} - t_{y_1,pC}$$

Equation 31

Where:

CL = cycle length (in seconds)

p = phase, derived from event parameter of cycle events

C = individual cycle

t_g = timestamp for start of green interval (EC 1)

t_{ey} = timestamp for end of yellow clearance interval (EC 9)

Step 3: Determine Total Ped Presses

During this step, the event log is queried to find all the EC 90 events within the analysis period where the Event Parameters match the detector channels for the given phase and approach or the protected phase number depending on whether there is a different pedestrian detector set up in the signal configuration. The total number of detector activations for the approach are summed over the analysis period of interest to determine the total ped presses.

$$PP_A = \sum_i |P_i|_0^t$$

Equation 32

Where:

A = approach at an intersection

P = individual pedestrian as defined by pedestrian detector on event (EC 90)

i = individual detector channel from approach A, derived from event parameter of detector on events (EC 90)

t = analysis period

Step 4: Determine Time Buffered X Second Presses

During this step the ped presses (EC 90) within a buffer time are combined and presented as one unique count. This is done to filter out multiple actuation events for the same pedestrian. The total number of time buffered X second presses for the approach are summed over the analysis period of interest to estimate the total unique pedestrian detections. Default for the buffer time is 15 seconds. To calculate the time buffered 15 second presses, all ped presses (EC 90) and their timestamps for each phase are recorded. 15 sec bins are built and a "baseline EC 90" is defined where the baseline EC 90 is either a) the first EC 90 in the bin, or b) an EC 90 found within 15 seconds of the first EC 90, from the previous bin. In scenario (b) the first EC 90 is not included in the count. After a baseline EC 90 is selected, for the next 14.99 seconds, EC 90s are ignored. The next EC 90 after this is included and becomes the new baseline.

Step 5: Identify Cycles with Ped Requests

In this step, all the sequential pedestrian actuations (EC 90) in the same phase are combined for a given phase and only the first pedestrian actuation is considered. The event log is then queried to find all the pedestrian cycle event codes - EC 90, EC 21, and EC 22. The event sequencing is verified by stepping through the event codes one-by-one, while noting the following two events and their codes to form an event code sequence. Within this process there are three possible valid event sequences with the associate delay as follows:

1. If Event Code sequence = 21, 90, 22, the pedestrian delay = 0
2. If Event Code sequence = 22, 90, 21, see step 8
3. If Event Code sequence = 21, 90, 21, see step 8

For all other Event Code sequences where there is no valid pedestrian activation, the sequence is skipped. In case (1), the pedestrian delay is 0 as the requested phase is already present with enough remaining time for the pedestrian to complete the requested movement. In cases (2) and (3) the pedestrian delay is calculated in step 8.

Cycles with Ped Requests is calculated by summing the number of pedestrian actuations with a query to find records where the Event Code is 90 followed by a pedestrian cycle.

Step 6: Determine Percent Pedestrian Recall

Ped Recall values for a given period are calculated by dividing the number of begin walks (EC 21) by the number of valid cycles (as discussed in Step 2).

Equation 33

$$PR = \frac{|W_A|_0^t}{|CL_{pC}|}$$

Where:

A = approach at an intersection

W = ped begin walk event for approach A (EC 21)

CL_{pC} = cycle length for approach A, derived on Eq 31

t = analysis period

Step 7: Calculate Pedestrian Delay for Each Pedestrian Actuation

During this step, the delay is calculated for pedestrian actuations. This delay is the difference in timestamps between the time of the first actuation and the time of the start of the next pedestrian walk indication in the called direction. This is determined and reported based on the time of the first pedestrian actuation. To determine this, for each pedestrian actuation, find the same event parameter as the subject phase and calculate the pedestrian delay as follows:

Equation 34

$$d_{ped,i} = (t_{pp,i}) - (t_{pc,i})$$

Where $t_{pp,C_{ped}} \geq t_{pc,i}$ and

d_{ped} = pedestrian delay (in seconds)

i = pedestrian actuation i

t_{pp} = time stamp of pedestrian begin walk (EC 21)

t_{pc} = time stamp of first ped detector activation (EC 90)

Step 8: Determine Minimum Delay, Maximum Delay, Average Delay and Percent Delay

In this step, delay statistics are calculated over the requested time period. Minimum delay is determined as the pedestrian event with the smallest amount of delay calculated in Step 3, while the Maximum Delay is determined as the pedestrian event with the largest amount of delay calculated in Step 3. The Average Delay is calculated by summing the total amount of delay for each pedestrian event and dividing by the number of events.

Percent Delay is calculated by summing the total amount of delay for each pedestrian event and dividing by the cycle length in Step 2.

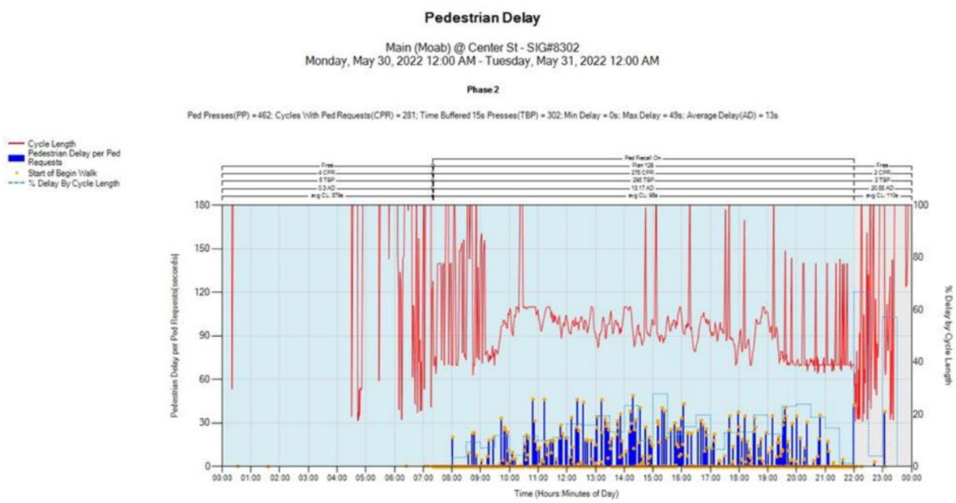
Equation 35

$$PD = \frac{d_{ped,i}}{CL_{pC}}$$

EXAMPLE

An example Pedestrian Delay diagram is shown in Exhibit 13. This example just includes one phase. Each signal will have a separate graph for each phase that accommodates pedestrians, typically displaying Pedestrian Delay for 4 phases.

Exhibit 13 Example Pedestrian Delay Diagram



7. YELLOW AND RED ACTUATIONS

OVERVIEW

This measure reports actuations on detectors located either at or past the stop bar relative to three phase states: yellow interval, red clearance interval, or red interval (after the beginning of the next phase). The actuation times can be used to estimate the number of vehicles entering the intersection during the yellow and red intervals and the amount of time into the red interval that the events occurred. A large number of potential violations (i.e., actuations during the red and red clearance intervals) is an indicator that the intersection may benefit from a safety evaluation and/or signal timing adjustments. (*1*).

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the yellow and red actuations measure. The data are listed in Exhibit 14.

Exhibit 14 Required Input Data for Yellow and Red Actuations Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 1 – Phase Begin Green EC 8 – Phase Begin Yellow Change EC 9 – Phase End Yellow Change EC 11 – Phase End of Red Clear	
Detector Activation*	EC 82 – Detector On	
Detector Channel	Field [DetChannel] in Detector Table	Must be provided and is associated with each required EC
Latency correction, s	Field [LatencyCorrection] in Detectors Table	Adjustment factor to account for latency between vehicle entering detection zone and the Detector On input being recorded in the controller

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

This measure determines yellow light occurrences, red light violations, and severe red-light violations. It should be noted that all the "violations" calculated in different steps are "potential" violations. Because although the high-resolution data is very close to the actual timestamps, due to latency issues the timestamp may vary a fraction of second and hence the measure cannot guarantee there was a violation.

The calculation framework for yellow and red actuations is:

1. Identify and adjust vehicle activations
2. Identify the start and end of each cycle
3. Identify bad cycles and bad data
4. Determine volume per period
5. Identify the beginning of red clearance for each cycle
6. Identify the beginning of red for each cycle
7. Identify the end of red for each cycle

8. Calculate yellow light occurrence values
9. Calculate red light violation values
10. Calculate severe red-light violation values

COMPUTATIONAL STEPS

Step 1: Identify and Adjust Vehicle Activations

During this step, the vehicle actuation events are extracted from the high-resolution event log. The event log is queried to find the events where the Event Code is 82 and the timestamps and Event Parameter (EP) of the requests are noted. Timestamps for detector on events may need to be adjusted to standardize vehicle arrivals based on possible latency differences. The offset correction is calculated as follows:

Equation 36

$$t_{adjva,v} = t_{va,v} - lc$$

t_{adjva} = adjusted time stamp of arrival time

v = vehicle v as defined by detector on event (EC 82)

t_{va} = time stamp of arrival time (EC 82)

lc = latency correction, based on system latency factors

The adjusted vehicle arrival time ($t_{adjva,v}$) is used for all the following computational steps.

Step 2: Identify the Beginning and End of Each Cycle

For the Yellow-Red Actuations measure, the beginning of the cycle for a given phase is defined as the start of yellow clearance interval (EC 8). The event log is queried to find the records where the Event Code is 8. Each instance of EC 8 is classified as the start of a cycle and the next instance of EC 8 is classified as the end of that same cycle. Events for this measure (*i.e.*, change to yellow, change to red, and end of the cycle) are calculated in reference to the start of the cycle (EC 8).

Step 3: Identify Valid Cycles

During this step, the event log is queried to find the cycle events for each phase and their timestamps for the Yellow-Red Actuations measure: start of yellow clearance interval (EC 8), end of yellow clearance interval (EC 9), end of red clearance event (EC 11), and start of green interval (EC 1) identified as the end of red. A valid cycle consists of first instance of EC 8 (cycle start), EC 9, EC 1, and second instance of EC 8 (cycle end), in that sequence. Any cycles without this sequence are excluded from further analysis. Adjusted timestamp for EC 82 ($t_{adjva,v}$ in Step 1) can be any time between the start and end of a cycle.

Step 4: Determine Volume per Period

The volume for each interval is calculated by summing the total number of vehicle actuations mentioned in step 1 within the user specified time bins (usually 5 or 15 minutes). These volumes are later used in percent calculations.

Step 5: Identify the Beginning of Red Clearance for Each Cycle

During this step, the event log is queried to find the records where the Event Code is 9. The duration from the beginning of the cycle to when the given phase changes to red (total yellow change interval) is calculated in reference to the first yellow event (begin) of the cycle, as follows:

$$RC_{pC} = t_{ey,pC} - t_{y_1,pC}$$ **Equation 37**

Where:

RC = start of red clearance time (in seconds)

p = phase, derived from event parameter of cycle events

C = individual cycle

t_{y_1} = timestamp for the first start of yellow clearance interval (EC 8)

t_{ey} = timestamp for end of yellow clearance interval (EC 9)

Step 6: Identify the Beginning of Red for Each Cycle

During this step, the event log is queried to find the records where the Event Code is 11. The duration from the beginning of the cycle to when the given phase changes to end of red clearance (total red clearance interval) is calculated in reference to the first yellow event (begin) of the cycle, as follows:

$$R_{pC} = t_{erc,pC} - t_{y_1,pC}$$ **Equation 38**

Where:

R = start of red time (in seconds)

p = phase, derived from event parameter of cycle events

C = individual cycle

t_{y_1} = timestamp for the first start of yellow clearance interval (EC 8)

$t_{erc,C}$ = timestamp for end of red clearance (EC 11)

Step 7: Identify the End of Red for Each Cycle

During this step, the event log is queried to find the records where the Event Code is 1. The duration from the beginning of the cycle to when the given phase changes to green (total red interval) is calculated in reference to the first yellow event (begin) of the cycle, as follows:

$$ER_{pC} = t_{y_1,pC} - t_{g,pC}$$ **Equation 39**

Where:

ER = end of red time (in seconds)

p = phase, derived from event parameter of cycle events

C = individual cycle

t_g = time stamp for start of green interval (EC 1)

t_{y_1} = timestamp for the first start of yellow clearance interval (EC 8)

Step 8: Calculate Yellow Light Occurrence Values

During this step, yellow light occurrences for each cycle are identified. The event log is queried to find events where the Event Code 82 occurs within the yellow change interval. These yellow occurrences are used in the calculation of the values for Yellow Light Occurrences (YLO), Percent Yellow Light Occurrences (%YLO), and Average Time Yellow Occurrences (TYLO).

The calculation of YLO, within user specified time bins, is as follows:

Equation 40

$$YLO_p = \sum_i \sum_{C=1}^{C=n} |VA_{iC}|_0^t$$

Where $t_{y_1,pC} \geq t_{adjva,vi} > t_{ey,pC}$ and

YLO = yellow light occurrence

VA = vehicle actuations (EC 82)

t_{adjva} = adjusted time stamp of arrival time

t_{y_1} = timestamp for the first start of yellow clearance interval (EC 8)

t_{ey} = timestamp for end of yellow clearance interval (EC 9) during cycle C

p = phase, represented by event parameter of cycle events

v = individual vehicle

i = individual detector channel i, represented by event parameter of detector on events (EC 82)

C = individual cycle, ranging from 1 to n

n = number of cycles

t = analysis period

The calculation of %YLO, is as follows:

Equation 41

$$\%YLO_p = \frac{YLO_{pt}}{\sum_i \sum_{C=1}^{C=n} |VA_{iC}|_0^t} \times 100\%$$

Where:

$\%YLO$ = percent yellow light occurrence (in percentage)

YLO = yellow light occurrence (Equation 36)

p = phase, derived from event parameter of cycle events

i = individual detector channel i, derived from event parameter of detector on events (EC 82)

C = individual cycle, ranging from *1* to n

n = number of cycles

VA = vehicle actuations (EC 82)

The calculation of TYLO, within user specified time bins, is as follows:

Equation 42

$$TYLO_{pt} = \frac{\sum_i \sum_C \sum_k (t_{YLO,kCi} - t_{y1,Cp})}{YLO_{pt}}$$

Where:

$TYLO$= average time yellow occurrences (in seconds) (EC 82)

YLO = yellow light occurrence (Equation 36)

t_{YLO} = timestamp of yellow occurrence

k = individual yellow occurrence event, ranging from 0 to YLO

t_{y_1} = timestamp for the first begin of yellow clearance interval (EC 8)

p = phase, derived from event parameter of cycle events

i = individual detector channel i, derived from event parameter of detector on events (EC 82)

C = individual cycle, ranging from 1 to n

t = analysis period

Step 9: Calculate Potential Red Light Violation Values

During this step, potential red light violations are identified. The event log is queried to find events where the Event Code 82 occurs within the red interval to be used in the calculation of the values; Red Light Violation (RLV), Percent Red Light Violation (%RLV), and Average Time Red Light Violation (Ave TRLV).

The calculation of RLV, is as follows:

Equation 43

$$RLV_p = \sum_{i} \sum_{C=1}^{C=n} |VA_{iC}|_0^t$$

Where $t_{ey,pC} \geq t_{adjva,vi} > t_{g,pC}$ and

YLO = yellow light occurrence for phase p within analysis period t

VA = vehicle actuations (EC 82)

t_{adjva} = adjusted time stamp of arrival time

t_{ey} = timestamp for end of yellow clearance interval (EC 9) during cycle C

t_g = timestamp for start of green interval (EC 1) during cycle C

p = phase, represented by event parameter of cycle events

v = individual vehicle

i = individual detector channel i, represented by event parameter of detector on events (EC 82)

C = individual cycle, ranging from 1 to n

n = number of cycles within

t = analysis period

The calculation of %RLV, is as follows:

Equation 44

$$\%RLV = \frac{RLV_{pt}}{\sum_{C=1}^{C=n} \left|TVA_p\right|_0^t} \times 100\%$$

Where:

$\%RLV$ = percent red light violations (in percentage)

RLV = red light violations (**Error! Reference source not found.**)

p = phase, derived from event parameter of cycle events

i = individual detector channel, derived from event parameter of detector on events (EC 82)

C = individual cycle, ranging from *1* to n

n = number of cycles

t = analysis period

VA = vehicle actuations for detector *i* (EC 82)

The calculation of TRLV, is as follows:

Equation 45

$$TRLV_{pt} = \frac{\sum_i \sum_C \sum_k \left(t_{RLV,iCk} - t_{ey,Cp}\right)}{RLV_{pt}}$$

Where:

$TRLV$ = average time red light violation (in seconds)

RLV = red light violations as per **Error! Reference source not found.**

t_{RLV} = time stamp of each red light violation

k = individual red light violation, ranging from 0 to RLV

t_{ey} = timestamp for end of yellow clearance interval (EC 9)

p = phase, derived from event parameter of cycle events

t = analysis period

i = individual detector channel, derived from event parameter of detector on events (EC 82)

C = individual cycle, ranging from *1* to n

Step 10: Calculate Potential Severe Red-Light Violation Values

During this step, severe red-light violations are identified. The severe red-light violation period is identified as 4 seconds after begin red clearance (Event Code 9) until end of red (Event Code 1). The event log is queried to find events where the Event Code 82 occurs within the red interval and 4 seconds after the start of red clearance to be used in the calculation of the values; Severe Red Light Violation (SRLV) and Percent Severe Red Light Violation (%SRLV).

The calculation of SRLV, is as follows:

Equation 46

$$SRLV_{i,t} = \sum_i \sum_{C=1}^{C=n} \left|VA_{i,t}\right|_0^t$$

Where $t_{ey,Cp} + 4\ sec \geq t_{adjva,vi} > t_{g,Cp}$ and

$SRLV$ = severe red light violations

t_{adjva} = adjusted time stamp of arrival time

t_{ey} = timestamp for end of yellow clearance interval (EC 9)

t_g = timestamp for start of green interval (EC 1)

C = individual cycle, ranging from *1* to n

p = phase, derived from event parameter of cycle events

i = individual detector channel, derived from event parameter of detector on events (EC 82)

VA = vehicle actuations (EC 82)

The calculation of %SRLV, is as follows:

Equation 47

$$\%SRLV_{pt} = \frac{SRLV_{pt}}{\sum_i \sum_{C=1}^{C=n} |VA_{iC}|_0^t} \times 100\%$$

Where:

$\%SRLV$= severe red-light violation (in percentage)

$SRLV$ = severe red-light violation (Equation 42)

p = phase, derived from event parameter of cycle events

i = individual detector channel, derived from event parameter of detector on events (EC 82)

C = individual cycle, ranging from *1* to n

n = number of cycles

t = analysis period

VA = vehicle actuations (EC 82)

EXAMPLE

An example of a Yellow and Red Actuations graph is shown in Exhibit 15. This is an example of one protected phase. Each movement type (through movement and left turn movement) gets a separate graph. The example shows the yellow change, red clearance, and red intervals as shaded horizontal sections with each occurrence plotted relative to the start of yellow change interval. The calculated values are shown at the top of the chart based on time-of-day plans.

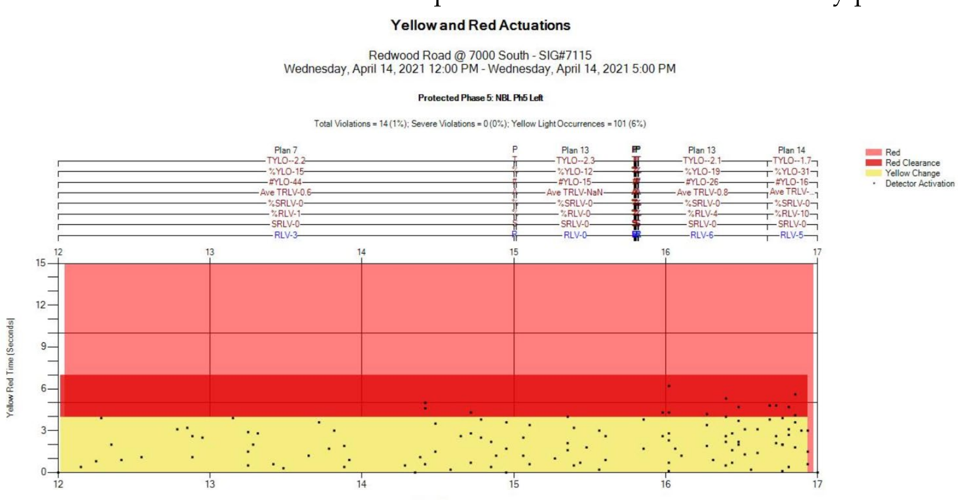


Exhibit 15 Example Yellow and Red Actuations Diagram

8. PURDUE COORDINATION DIAGRAM

OVERVIEW

The Purdue Coordination Diagram provides additional details on vehicle arrivals during the cycle (e.g., during the green phase or red phase for each approach). The percent arrival on green, platoon ratio, and arrival type can help identify locations that would benefit from adjustments to signal timing (i.e., to cycle lengths, splits, offsets, and phase order), and the Purdue Coordination Diagram can help identify the values that should be chosen for those adjustments. It can also be used to monitor general intersection operations. With the cycle length being displayed in the diagram, this measure can be useful for monitoring advanced applications such as traffic responsive or adaptive control (*1*). For Purdue Coordination Diagrams ATSPM defines the cycle from the beginning of the red interval to the beginning of the next red interval for the same phase. This measure can only be generated for approaches with advance detection.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the Purdue coordination diagram measure. The data are listed in Exhibit 16.

Exhibit 16 Required Input Data for Purdue Coordination Diagram Measure

Required Data and Units	Source Data	Notes
Detector Activations*	EC 82 – Detector On	
Phase Interval Changes*	EC 1 – Phase Begin Green EC 8 – Phase Begin Yellow Change EC 9 – Phase End Yellow Change	
Detector setback, ft	Field [DistanceFromStopBar] in Detector Table	Measured from leading edge of detector top stop bar
Approach speed, mph	Field [MPH] in Approaches Table	Speed limit of roadway
Latency correction, s	Field [LatencyCorrection] in Detector Table	Adjustment factor to account for latency between vehicle entering detection zone and the Detector On input being recorded in the controller

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

The Purdue Coordination Diagram measure displays both signal-related measures (such as phase changes) and vehicle-related measures (such as arrivals and volume). For this measure, the cycles are evaluated from the beginning of the red interval to the beginning of the next red interval. The time when each event occurs within each cycle is therefore determined by taking the difference between the timestamp of each event and the beginning of the previous red interval. For signal-related events this time is then used to determine the green, yellow, and red intervals within the cycle.

The vehicle-related measures are determined by summing vehicle detector actuations during the appropriate time periods. The calculation framework is as follows:

1. Identify and adjust (if necessary) vehicle actuations
2. Determine volume per hour from vehicle actuations
3. Identify the beginning of each cycle
4. Identify the time of the change to green for each cycle
5. Identify the time of the change to yellow for each cycle
6. Identify the time of the change to red at the end of each cycle
7. Calculate the percentage of arrivals on green
8. Calculate the percentage of green time
9. Calculate the platoon ratio based on the arrival on green and green time measures

COMPUTATIONAL STEPS

Step 1: Identify and Adjust Vehicle Actuations

During this step, the event log is queried to find detector activations for the subject phase (the records where the Event Code is 82 and Event Parameter is a detector channel assigned to the subject phase). The timestamps of the EC 82 events are noted. Timestamps for detector on events may need to be adjusted to represent vehicle arrivals at the stop bar rather than at the detector location or to adjust based on possible detector latency differences. The adjusted arrival times are calculated as follows using offset and latency corrections:

Equation 48

$$t_{adjva,v} = t_{va,v} + \frac{d}{s \times 1.467} - lc$$

Where:

t_{adjva} = adjusted time stamp of arrival time

v = individual vehicle as defined by detector on event (EC 82)

t_{va} = time stamp of arrival time (EC 82)

d = stated distance to stop bar

s = stated speed for the approach

lc = latency correction, based on system latency factors

The adjusted vehicle arrival time ($t_{adjva,v}$) is used for all the following computational steps.

Step 2: Determine Volume per Hour

The volume for each interval (standardized to volume per hour) is calculated by summing the total number of vehicle actuations within the user specified time bins (currently limited to either 5- or 15-minute bins). These volumes are standardized to the equivalent volume per hour by multiplying by 4 (for 15-minute bins) or by 12 (for 5 -minute bins).

Step 3: Identify the Beginning of Each Cycle

For the Purdue Coordination Diagram measure, the beginning of the cycle for a given phase is defined as the end of yellow clearance interval (EC 9). The event log is queried to find the records where the Event Code is 9. Each instance of EC 9 is indicated as the start of the cycle. The extents of the cycle used for the inclusion detector activation and the baseline to the change to green, change to yellow, and end of the cycle are calculated in reference to this first red event.

Step 4: Identify the Change to Green for Each Cycle

During this step, the event log is queried to find the records where the Event Code is 1. The duration from the beginning of the cycle to when the given phase changes to green (total red interval) is calculated in reference to the first red event (begin) of the cycle, as follows:

Equation 49

$$G_{pC} = t_{g,C} - t_{ey_1,C}$$

Where:

G = time (in seconds) to the change to green

p = phase, derived from event parameter of the cycle events

C = individual cycle

t_g = timestamp for start of green interval (EC 1)

t_{ey_1} = timestamp for first end of yellow clearance interval (EC 9)

Step 5: Identify the Change to Yellow for Each Cycle

During this step, the event log is queried to find the record where the Event Code is 8. The duration from the beginning of the cycle to when the given phase changes to yellow (total green interval) is calculated in reference to the first red event (begin) of the cycle, as follows:

Equation 50

$$Y_{pC} = t_{y,C} - t_{ey_1,C}$$

Where:

Y = time (in seconds) to the change to yellow

p = phase, derived from event parameter of the cycle events

C = individual cycle

t_y = timestamp for start of yellow clearance interval (EC 8)

t_{ey_1} = timestamp for first end of yellow clearance interval (EC 9)

Step 6: Identify the Change to Red at the End of Each Cycle

During this step, the event log is queried to find the records where the Event Code is 9. The duration from the beginning of the cycle to when the given phase changes to red (yellow clearance interval) is calculated in reference to the first red event (begin) of the cycle, as follows:

Equation 51

$$R_{pC} = t_{ey_2,C} - t_{ey_1,C}$$

Where:

R = time (in seconds) to the change to red

p = phase, derived from event parameter of the cycle events

C = individual cycle

t_{ey_1} = timestamp for first end of yellow clearance interval (EC 9)

t_{ey_2} = timestamp for second end of yellow clearance interval (EC 9, equivalent to t_{ey_1} of the following cycle for that phase)

Step 7: Calculate Arrival on Green (AoG)

The AoG is the proportion of the number of vehicle actuations occurring during green phases (arrival on green) to the total volume of vehicle actuations occurring during the cycle.

Equation 52

$$A_{g,pt} = \sum_{i} \sum_{C=1}^{C=n} |VA_{iC}|_0^t$$

Where $t_{y,pC} > t_{adjva,vi} \geq t_{g,pC}$ and

- A_g = arrival on green
- p = phase, derived from event parameter of cycle events
- i = individual detector channel, derived from event parameter of detector on events (EC 82)
- C = individual cycle, ranging from *1* to n
- n = number of cycles
- t = analysis period
- VA = vehicle actuations (EC 82)

Equation 53

$$AoG_{pt} = \frac{A_{g,pt}}{\sum_i \sum_{C=1}^{C=n} |VA_{iC}|_0^t} \times 100\%$$

Where:

- AoG = arrival on green (in percentage)
- $A_{g,pt}$ = arrival on green within analysis period *t* for phase *p* (Equation 52)
- VA_i = vehicle actuations for detector channel *i* within analysis period *t* (EC 82)

Step 8: Calculate Percent Green Time (GT)

The GT is the proportion of the amount of time given to green phases in the specified time period to the total amount of time in the same period.

Equation 54

$$GT_{pt} = \frac{\sum_C t_{g,C} - t_{ey_1,C}}{\sum_C \left(t_{y_2,C} - t_{y_1,C}\right)} \times 100\%$$

Where:

- GT = proportion of green time (in percentage)
- p = phase derived from event parameter of cycle events
- C = individual cycle
- t_g = timestamp for start of green interval (EC 1)
- t_{ey_1} = timestamp for first end of yellow clearance interval (EC 9)
- t_{ey_2} = timestamp for second end of yellow clearance interval (EC 9, equivalent to t_{ey_1} of the following cycle for that phase)

t = analysis period

Step 9: Calculate Platoon Ratio (PR)

The PR is the proportion of the AoG to the GT.

Equation 55

$$PR_{pt} = {AoG_{pt}}/{GT_{pt}}$$

Where:

PR = proportion of green time (in decimal)

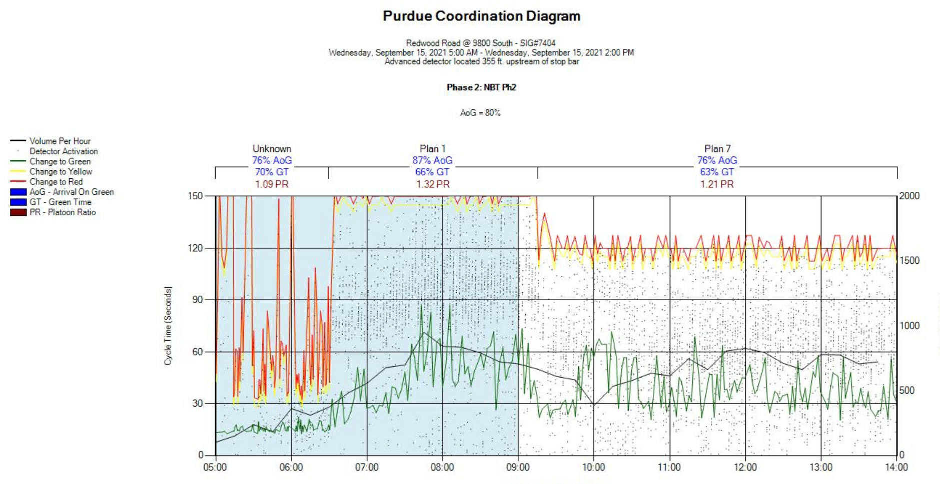
AoG_{pt} = arrival on green (in percentage) within analysis period t for phase p (Equation 49)

GT_{pt} = proportion of green time (in percentage) within analysis period t for phase p (Equation 50)

EXAMPLE

An example Purdue Coordination Diagram is shown in Exhibit 17. This example shows only one phase. Each signal displays a diagram for each through phase that has the appropriate detection on the corresponding approaches.

Exhibit 17 Example Purdue Coordination Diagram



9. PREEMPTION DETAILS

OVERVIEW

Preemption is the interruption of normal operations to serve a preferred vehicle (e.g., train, emergency vehicle). This measure can be used to determine if preemption events are occurring as intended. “Preemption Details” refers to the duration of preemption intervals for each preemption event. The type of interval information available depends on the type of preempt (i.e., rail or emergency vehicle) and the availability of certain inputs. Some potential intervals that can be tracked include entry delay, track clearance, gate down, dwell, time to service, max-out, and preempt input on/off (*1*).

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the preemption details measure. The data are listed in Exhibit 18.

Exhibit 18 Required Input Data for Preemption Details Measure

Required Data and Units	Source Data	Notes
Preempt Number	Event Parameter	Must be provided
Preemption Details*	EC 102 – Input On EC 103 – Gate Down EC 104 – Input Off EC 105 – Preempt Entry Starter EC 107 – Begin Dwell Service EC 110 – Call Max Out EC 111 – Cycle End	

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

The preemption details measure displays information about signal preemption, primarily by rail. The calculation framework is as follows:

1. Calculate dwell time
2. Calculate track clear time
3. Calculate time to service
4. Calculate delay
5. Identify preempt gate down
6. Identify preempt call max out

COMPUTATIONAL STEPS

Step 1: Calculate Dwell Time

For each preempt service, the dwell time is calculated. The dwell time is defined as the time elapsed from the beginning of the dwell service for the preemption to the beginning of the preemption exit interval. The event log is queried to find events where the Event Code is 111 (to find the exit interval) and 107 (to find the beginning of the dwell service). The dwell time is calculated as follows:

$$T_{dt,i} = (t_{ec,i}) - (t_{bd,i})$$

Equation 56

Where:

T_{dt} = dwell time (in seconds)

i = preempt number, represented by the event parameter

t_{ec} = time stamp of the beginning of the exit interval (EC 111)

t_{bd} = time stamp of begin of dwell service (EC 107)

Step 2: Calculate Track Clear Time

For each preempt service, the track clear time is calculated. The track clear time is defined as the time from the beginning of the track clearance to the beginning of the dwell service. The event log is queried to find events where the Event Code is 106 (to find beginning of the track clearance and 107 (to find the beginning of the dwell service). The track clear time is calculated as follows:

Equation 57

$$T_{tc,i} = (t_{bd,i}) - (t_{tc,i})$$

Where:

T_{tc} = track clear time (in seconds)

i = preempt number, represented by the event parameter

t_{bd} = time stamp of begin of dwell service (EC 107)

t_{tc} = time stamp of begin track clearance (EC 106)

Step 3: Calculate Time to Service

For each preempt service, the time to service is calculated. The time to service is defined as the time from beginning of the preemption request to the beginning of the dwell service. The event log is queried to find events where the Event Code is 102 (to find the preemption input call) and 107 (to find the beginning of the dwell service). The time to service is calculated as follows:

Equation 58

$$T_{ts,i} = (t_{bd,i}) - (t_{bc,i})$$

Where:

T_{ts} = time to service (in seconds)

i = preempt number, represented by the event parameter

t_{bd} = time stamp of begin of dwell service (EC 107)

t_{bc} = time stamp of preemption input call (EC 102)

Step 4: Calculate Delay

For each preempt service, the delay is calculated. The delay is defined as the time from beginning of the preemption input on to the entry start. The event log is queried to find events where the Event Code is 102 (to find the beginning of the cycle) and 105 (to find the entry start). The delay is calculated as follows:

Equation 59

$$T_{d,i} = (t_{es,i}) - (t_{bc,i})$$

Where:

T_d = delay (in seconds) f

i = preempt number, represented by the event parameter

t_{es} = time stamp of entry start (EC 105)

t_{bc} = time stamp of preemption input call (EC 102)

Step 5: Calculate Time to Gate Down

During this step, the event log is queried to find the records where Event Code is 103, the preempt gate down events. The timestamp of these Event Codes is noted. The time to gate down is calculated as follows:

$$T_{tg,i} = (t_{g,i}) - (t_{bc,i})$$

Equation 60

Where:

T_{tg} = time to gate down (in seconds) f

i = preempt number, represented by the event parameter

t_g = time stamp of gate down (EC 103)

t_{bc} = time stamp of preemption input call (EC 102)

Step 6: Calculate Time to Call Max Out

During this step, the event log is queried to find the records where Event Code is 110, the preempt max presence exceeded events. The timestamp of these Event Codes is noted. The time to call max out is calculated as follows:

$$T_{tm,i} = (t_{bd,i}) - (t_{bc,i})$$

Equation 61

Where:

T_{tg} = time to gate down (in seconds)

i = preempt number, represented by the event parameter

t_{mo} = time stamp of max out call (EC 110)

t_{bc} = time stamp of preemption input call (EC 102)

EXAMPLE

An example preemption details measure diagram is shown in Exhibit 18. This graph shows what kind of preemption was requested, how long it took to service the request, and how long it took the preempt service to end.

Ex Pr Di

10. APPROACH SPEED

OVERVIEW

Vehicle speed is a measure that can be shared with decision-makers and the public to effectively communicate signal timing impacts on traffic. It can also be used to prioritize signal timing activities where approach speeds are lower than the rest of the corridor (*1*). The measure reported in ATSPM can also be used to approximate speed distributions along the corridor, as speeds are only recorded for vehicles travelling over X mph (5 mph is default) that occur between 15 seconds after the start of green to the start of yellow. This measure displays the average speed, 15th percentile speed, and 85th percentile speed, along with the posted speed limit.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the approach speed measure. The data are listed in Exhibit 20.

Exhibit 20 Required Input Data for Approach Speed Measure

The speed data is not collected as part of the high-resolution data. Must have speed capable detectors to log directly to the speed table.

Required Data and Units	Source Data	Notes
Detector Setback, ft	Field [DistanceFromStopBar] in Detector Table	Located beyond the initial queue of vehicles; approximately 350-400 feet
Phase Interval Changes*	EC 1 – Phase Begin Green EC 8 – Phase Begin Yellow Change	Phase Interval Changes*
Speed (MPH)	Field [MPH] in Speed_Events Table	
Detector setback, ft	Field [DistanceFromStopBar] in Detector Table	Measured from leading edge of detector top stop bar
DetectorID	Field [DetectorID] in Speed_Events Table	Used to join table to High-Resolution data
Approach speed, mph	Field [MPH] in Approaches Table	Speed limit of roadway

Notes: EC = Event Code
*All data for EC code are stored in controlled event log table

OVERVIEW OF THE METHODOLOGY

This measure identifies what the speeds are when a vehicle is approaching an intersection during a set amount of time from the green interval to the beginning of the yellow interval. The speed data is not part of the high-resolution data and is logged directly to the tables from the detectors. The computation framework goes as follows:

1. Calculate average speed
2. Calculate standard deviation of average
3. Calculate 85th percentile
4. Calculate 15th percentile

COMPUTATIONAL STEPS

Step 1: Calculate Average Speed

In this step, the event log is queried to find the speed data for every detector activation in the analysis period. To get the average speed, the sum of all the speeds is divided by the number of speed events the detector records. The result of this equation is rounded to the nearest whole number.

Equation 62

$$S_{avg} = \frac{\sum_{a_i}^{b_i} S}{|SE|_{a_i}^{b_i}}$$

Where $S \geq$ X mph (default is 5 mph) and:

S_{avg} = average speed (in MPH)

a = timestamp for start of green interval (EC 1) + 15 seconds

b = timestamp for begin of yellow clearance (EC 8)

i = Directionality based in approach and detector data

SE = individual speed events or Detector activations (EC 82)

S = vehicle speed in MPH of individual speed events

Step 2: Calculate the Standard Deviation of the Average

This step shows the equation of finding the standard deviation of the average. This equation will be rounded to the nearest whole number after a result is found.

Equation 63

$$SD_{spd} = \sqrt{\frac{\sum_{SE}\left(S_{SE} - S_{avg}\right)^2}{|SE|_{a_i}^{b_i}}}$$

Where $Spd \geq 5$ and:

SD_{spd} = standard deviation of speed

S = vehicle speed in MPH of individual speed events

S_{avg} = average speed (in MPH)

a = Start time from timestamp or start of green interval (EC 1)

b = End time from timestamp of start of yellow clearance interval (EC 8)

i = Directionality based in approach and detector data

SE = individual speed events or detector activations (EC 82)

Step 3: Calculate 85th Percentile

With speed counts higher than three, the list of speed found in the time period get sorted in numerical order. The percentile index is found using:

Equation 64

$$PI = (|SE| \times .85 - 1) + .5$$

Where:

PI = Percentile Index

SE = individual speed events or Detector activations (EC 82)

The percentile index is rounded to the nearest whole number. The rounded percentile index is used to find what speed in which it corresponds to in the list.

If the speed count is less than 3, the percentile index is found using Equation 36 and rounded to the nearest whole number. The equation for 85th percentile with speed counts less than 3 is:

$$Raw\ 85th = \frac{(S_1 + S_2)}{2}$$ **Equation 65**

Where:

S_1 = speed corresponding to [percentile index]

S_2 = speed corresponding to [percentile index + 1]

The value of $Raw\ 85th$ is rounded to the nearest whole number.

Step 4: Calculate 15th Percentile

With speed counts higher than three, the list of speeds found in the time period are sorted in numerical order. The percentile index is found using:

$$PI = (|SE| \times .15 - 1) + .5$$ **Equation 66**

Where:

PI = Percentile Index

SE = individual speed events or Detector activations (EC 82)

The percentile index is rounded to the nearest whole number. The rounded percentile index is used to find what speed in which it corresponds to in the list.

If the speed count is less than 3, the percentile index is found using Equation 19 and rounded to the nearest whole number. The equation for 15th percentile with speed counts less than 3 is:

$$Raw\ 15th = \frac{(S_1 + S_2)}{2}$$ **Equation 67**

Where:

S_1 = speed corresponding to [percentile index]

S_2 = speed corresponding to [percentile index + 1]

The value of $Raw\ 15th$ is rounded to the nearest whole number.

EXAMPLE

An example of an approach speed measure diagram is shown in Exhibit 20. This graph shows one travel direction. Each travel direction at the intersection has its own unique graph. It shows the average, 85th, and 15th percentile speed limit and the standard deviation of speed for every different signal plan throughout the chosen time period. For the graph, it only counts cycles that start before or equal to the ending of the bin, takes the averages of the recorded speeds in the cycles, and makes it a point on the graph.

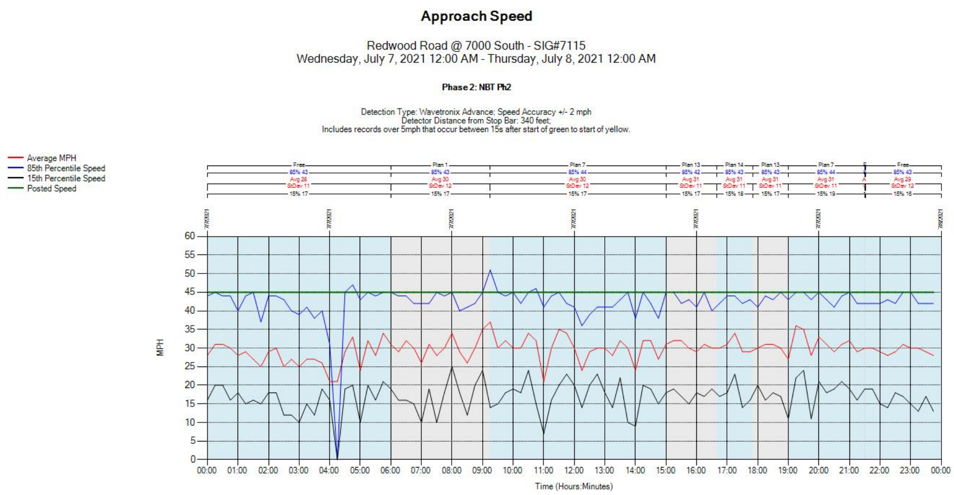


Exhibit 21 Example Approach Speed Diagram

11. ARRIVALS ON RED

OVERVIEW

Arrivals on red is a measure that can evaluate vehicle progression through coordinated signals. A large number of arrivals on red may result in longer travel times, longer queues, and sometimes excessive red-light running (*1*). This ATSPM measure reports the number of vehicles arriving on red and the number of total vehicles, along with the percentage of vehicles arriving on red and the percentage of red time.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the arrivals on red measure. The data are listed in Exhibit 22.

Exhibit 22 Required Input Data for Arrivals on Red Measure

Required Data and Units	Source Data	Notes
Detector Activation*	EC 82 – Detector On	
Phase Interval Changes*	EC 1 – Phase Begin Green EC 8 – Phase Begin Yellow Change EC 9 – Phase End Yellow Change EC 11 – Phase End of Red Clear	
Detector setback, ft	Field [DistanceFromStopBar] in Detector Table	Measured from leading edge of detector to stop bar
Approach speed, mph	Field [MPH] in Approaches Table	Speed limit of roadway
Latency correction, s	Field [LatencyCorrection] in Detector Table	Adjustment factor to account for latency between vehicle entering detection zone and the Detector On input being recorded in the controller
Phase	Event Parameter	Must be provided and is associated with each required EC

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

The Arrivals on Red (AoR) measure is computed by identifying vehicle actuations and whether they arrive at the signal during a red phase for the through phase on the approach. The computation framework is as follows:

1. Identify and adjust vehicle actuations
2. Identify the beginning of each cycle
3. Identify cycle events
4. Calculate total detector hits
5. Identify and calculate arrivals on red
6. Calculate red time
7. Determine volume per hour
8. Determine arrivals on red per hour

COMPUTATIONAL STEPS

Step 1: Identify and Adjust Vehicle Activations

During this step, the vehicle activation events are extracted from the high-resolution event log. The event log is queried to find the records where the Event Code is 82 and the timestamps of the requests are noted. Timestamps for detector on events may need to be adjusted to represent vehicle arrivals at the stop bar rather than at the detector location or to standardize based on possible latency differences. The adjusted arrival times are calculated as follows using offset and latency corrections:

Equation 68

$$t_{adjva,v} = t_{va,v} + \frac{d}{s \times 1.467} - lc$$

Where:

t_{adjva} = adjusted time stamp of arrival time

v = individual vehicle as defined by detector on event (EC 82)

t_{va} = time stamp of arrival time (EC 82)

d = stated distance to stop bar

s = stated speed for the approach

lc = latency correction, based on system latency factors

The adjusted vehicle arrival time ($t_{adjva,v}$) is used for all the following computational steps.

Step 2: Identify the Beginning of Each Cycle

For the Arrivals on Red measure, the beginning of the cycle is defined as the end of yellow clearance interval (EC 9). The event log is queried to find the events where the Event Code is 9. Each instance of EC 9 is indicated as the first red event of the cycle. The time in the cycle for detector activation, change to green, change to yellow, and change to red is calculated in reference to this first red event. The next red event in cycle *j* is considered the phase begin red event, which serves as the end of cycle *j* and the first red event of cycle *j+1*.

Step 3: Identify Cycle Events

During this step, cycle events for Arrivals on Red measure are identified and their time stamps are extracted from the high-resolution event log. Cycle events are – end of yellow clearance interval (EC 9), start of green interval (EC 1), and start of yellow clearance interval (EC 8). Within each cycle, first instance of EC 9 (cycle start), EC 1, EC 8 and second instance of EC 9 (end of cycle) need to follow this sequence based on their timestamps. Otherwise, the group of events is not included in further calculations. Adjusted timestamp for EC 82 ($t_{adjva,v}$ in Step 1) can be at any time between start and end of cycle.

Step 4: Calculate Total Arrivals

During the step, the event log is queried to find events where the Event Code 82 occurs within each and the events are classified as vehicle arrivals. The instances are then summed to find the total arrivals within the analysis period.

Equation 69

$$A_{total} = \sum_{i} \sum_{C=1}^{C=n} |VA_{iC}|_0^t$$

Where:

A_{total} = total vehicle arrivals

p = phase, derived from the event parameter for cycle events

i = individual detector channel, represented by event parameter of detector on events (EC 82)

C = individual cycle, ranging from *1* to n

n = number of cycles wit

t = analysis period

VA = vehicle actuations during cycle C (EC 82)

Based on the selection of bin, the metric may present discreet results.

Step 5: Identify and Calculate Arrivals on Red

During this step, arrivals on red are identified. The detector events that occur between end of yellow clearance interval (EC 9) and start of green interval (EC 1), also identified as end of red are classified as arrivals on red. Total arrival on red (AoR) is the number of vehicle actuations occurring during the red interval.

Equation 70

$$A_{r,pt} = \sum_{i} \sum_{C=1}^{C=n} |VA|_{i,t}$$

Where $t_{ey,Cp} \geq t_{adjva,vi} > t_{g,Cp}$ and

A_r = arrival on red

t_{adjvai}=adjusted time stamp of arrival time

t_{ey} = timestamp for end of yellow clearance interval (EC 9)

t_g = timestamp for start of green interval (EC 1)

p = phase, derived from the event parameter for cycle events

i = individual detector channel, represented by event parameter of detector on events (EC 82)

t = analysis period

VA = vehicle actuations for detector (EC 82)

The Percent Arrivals on Red (%AoR) is the proportion of the number of vehicle actuations occurring during red phases to the total number of vehicle actuations occurring during the cycle.

Equation 71

$$AoR = \frac{A_{r,pt}}{A_{total}} \times 100\%$$

Where:

AoR = arrival on red (in percentage)

$A_{r,pt}$ = arrival on red within analysis period t for phase p (Equation 66)

A_{total} = total vehicle arrivals (Equation 65)

p = phase, derived from the event parameter for cycle events

t = analysis period

Based on the selection of bin, the metric may present discreet results.

Step 6: Calculate Percent Red Time (RT)

The RT is the proportion of the amount of time given to red phases in the specified time period to the total amount of time in the same period.

Equation 72

$$RT_{pt} = \frac{\sum_C \left(t_{g,C} - t_{ey_1,C}\right)}{\sum_C \left(t_{ey_2,C} - t_{ey_1,C}\right)} \times 100\%$$

Where:

RT = proportion of red time (in percentage)

p = phase, derived from event parameter for cycle events

C = individual cycle

t_g = timestamp for start of green interval (EC 1)

t_{ey_1} = timestamp for first end of yellow clearance interval (EC 9)

t_{ey_2} = timestamp for second end of yellow clearance interval (EC 9, equivalent to t_{ey_1} of the following cycle for that phase)

Step 7: Determine Volume per Hour

The volume for each interval (standardized to volume per hour) is calculated by summing the total number of vehicle actuations within the user specified time bins (The code mandates 5 or 15 minute bins be used). These volumes are standardized to the equivalent volume per hour by multiplying by 4 (for 15-minute bins) or by 12 (for 5 -minute bins).

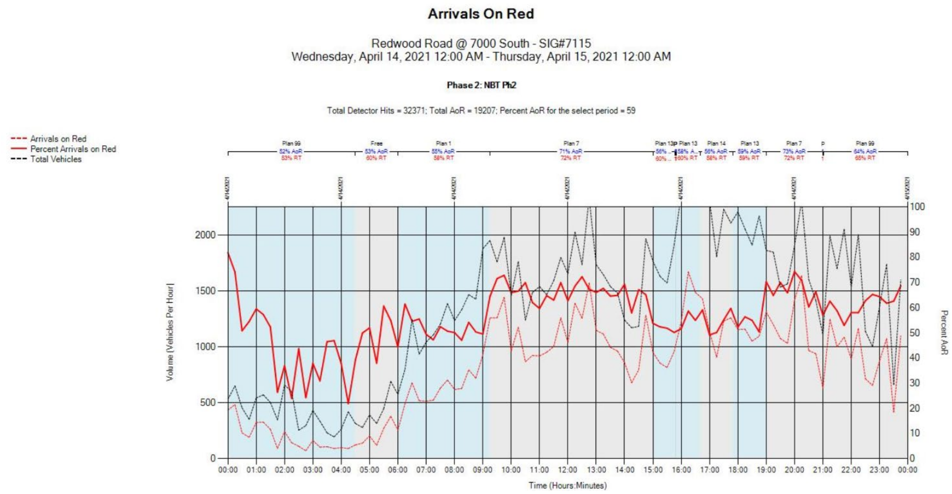
Step 8: Determine Arrivals on Red per Hour

The arrivals on red for each interval (standardized to volume per hour) is calculated by summing the total number of vehicle activations classified as arrival on red within the user specified time bins (5 or 15 minutes). These volumes are standardized to the equivalent volume per hour by multiplying by 4 (for 15-minute bins) or by 12 (for 5 -minute bins).

EXAMPLE

An example Arrivals on Red diagram is shown in Exhibit 23. This is an example for one approach. Each approach for a signal will have a separate graph to show arrivals on red.

Exhibit 23 Example Arrivals on Red Diagram



12. TURNING MOVEMENT COUNTS

OVERVIEW

Volume data can be useful for determining signal timing and numerous other traffic operation analysis (*1*). The turning movement counts measure provides volume data for each movement within an approach by lane based on count detectors located at the intersection.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the turning movement counts measure. The data are listed in Exhibit 24.

Exhibit 24 Required Input Data for Turning Movement Count Measure

Required Data and Units	Source Data	Notes
Detector Activation*	EC 82 – Detector On	
Detector Channel	Event Parameter Field [DetChannel] in Detector Table	
Approach ID	Field [ApproachID] in Approaches Table	
Detector ID	Field [DetectorID] in Detector Table	Used to join tables to High-Resolution data
Movement Type	Field [MovementTypeID] in Detector Table	Used to join tables
Direction Type	Field [DirectionTypeID] in Approaches Table	Used to join tables
Detector Type	Field [DetectionTypeID] in Detection Type Table	Used to join tables. Uses type 4 "Lane by Lane Count"

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

The turning movement counts determines the total number of vehicle detections occurring lane-by-lane by approach and movement type.

1. Calculate volume
2. Determine peak hour and peak hour volume
3. Calculate peak hour factor (PHF) and lane utilization factor (f_{LU})

COMPUTATIONAL STEPS

Step 1: Calculate Volume

In this step the lane-by-lane and total volumes are calculated. The event log is queried to find events where the Event Code is 82 (detector on) filtered base on detection type where type is Lane-by-Lane Count (detector type 4). The total number of detector activations (EC 82) in a lane for each detector are summed over the time-period of interest to determine the lane volume. Through-right and through-left lanes are considered through lanes in the charts for this measure but labeled TL and TR when the table is used. For movements with multiple lanes, the total lane group volume is calculated by summing the volume for each lane:

$$V_m = \sum_{l} |VA_l|_0^t$$

Equation 73

Where:

V_m = total movement volume for movement m

t = analysis period

l = lane number, derived from event parameter

VA = vehicle actuations

Step 2: Determine Peak Hour and Peak Hour Volume

The peak hour is determined within analysis period based on the bin size. The volumes for each bin are summed for progressive 60-minute periods to be used to determine the peak hour. The 60-minute aggregation of bins with the highest volume for the signal is identified as the peak hour for that signal. The volumes for these identified periods are determined to be the Peak Hour Volume.

Step 3: Calculate Lane Utilization Factor (fLU) and Peak Hour Factor (PHF)

The lane utilization factor is defined as the total volumes per lane group multiplied by the maximum lane volume. This factor is calculated for each movement type.

Equation 74

$$f_{lu} = \frac{V_m}{n * V_{l,max}}$$

Where:

V_m = total volume for movement (lane group) m

n = number of lanes

$V_{l,max}$ = highest per lane volume for movement m

The peak hour factor is defined as the peak hour volume (in vph) divided by the peak 15-minute flow rate (in vph). This is also calculated for each movement type.

Equation 75

$$PHF = \frac{V_{m,PH}}{4 \times V_{m,P15}}$$

Where:

PHF = peak hour factor for approach A

$V_{m,PH}$ = volume (in vph) of movement m during the peak hour

$V_{m,P15}$ = volume (in vph) of movement m during the peak 15 minutes of the peak hour

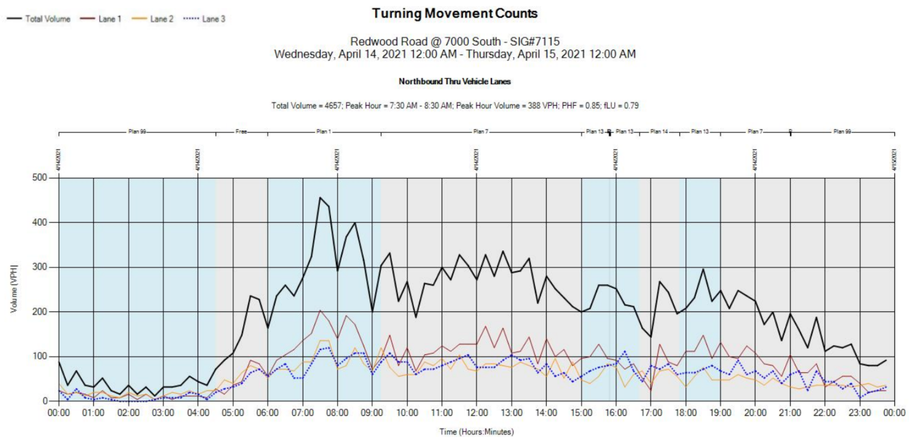
PH = peak hour for approach A

P_{15} = peak 15 minutes of the peak hour

EXAMPLE

An example Turning Movement Counts graph is shown in Exhibit 25. This is an example of a through lane. The through movement and left turn movement are displayed in separate graphs for each travel direction. The counts are also available in tabular form but are not shown here.

Exhibit 25 Example Turning Movement Counts Diagram



13. TIMING AND ACTUATION

OVERVIEW

Timing and actuation measure is used in analyzing and reconstructing a short duration of signal operation data. The timing and actuation metric is designed for detail and is written to analyze things on mesoscopic and microscopic levels of analysis. This data can be evaluated to determine if there were any red-light runners, the red-light duration and green light duration, and the most likely time of events at the signal. One application of this measure is reviewing signal operations during crashes or other incidents; this measure is also used in troubleshooting signal phasing and timing problems (*6*), and it has the flexibility to allow for other event codes to be displayed as desired by the user.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the timing and actuation measure. The data are listed in Exhibit 26.

Exhibit 26 Required Input Data for Timing and Actuation Measure

Required Data and Units	Source Data	Notes
Signal Event*	EC 1, EC 61 – Phase Begin Green EC 3, EC 62 – Phase End Minimum Green EC 8, EC 63 – Phase Begin Yellow EC 9, EC 64 – Phase End Yellow Change EC 11, EC 65 – Phase End Red Clear EC 21, EC 67 – Pedestrian Begin Walk EC 22, EC 68 – Pedestrian Begin Clearance EC 23, EC 69 – Pedestrian Begin Solid, Don't Walk	Events listed as typical event code, overlap event code
Detector Activation*	EC 81 – Detector Off EC 81 – Detector On EC 89 – Ped Detector Off EC 90 – Ped Detector On	
Detector Channel	Field [DetChannel] in Detectors Table	Must be provided and is associated with each required EC
Detector Type	Field [DetectionTypeID] in Detection Type Table	Used to join tables to high-resolution data. Uses type 2, 4, 6 and 8
Phase	Event Parameter	Must be provided and is associated with each required EC
Movement Type	Field [MovemetTypeID] in Detectors Table	Must be provided and is associated with each required EC
Lane Number	Field [LaneNumber] in Detectors Table	Must be provided and is associated with each required EC
Detector setback, ft	Field [DistanceFromStopBar] in Detector Table	Measure from leading edge of detector to stop bar

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

This measure determines the times and durations (if applicable) of the vehicle signal indications, pedestrian signal indications, vehicle detection (for each available detector), and pedestrian detection for each phase. These are all displayed graphically with colors for the signal indications and points for the detections.

The calculation framework for the timing and actuation measure is:

1. Display vehicle signal events
2. Identify pedestrian intervals
3. Identify pedestrian actuations
4. Identify stop bar presence activations
5. Identify lane-by-lane count activations
6. Identify advanced presence activations
7. Identify advanced count activations
8. Combine detectors activations for phases
9. Display raw data
10. Extend search (left)
11. Extend start/stop search

COMPUTATIONAL STEPS

Step 1: Display Vehicle Signal Events

During this step, signal events are identified, and time stamps are mapped. Signal events are listed in Exhibit 25.

Step 2: Identify Pedestrian Intervals

During this step, pedestrian interval events are identified, and time stamps are mapped. Pedestrian interval events are listed in Exhibit 25.

Step 3: Identify Pedestrian Actuations

During this step, pedestrian actuations are identified, and time stamps are mapped. Pedestrian actuation events are listed in Exhibit 25.

Step 4: Identify Stop Bar Presence Activations

During this step, stop bar presence activations are identified. Detector on (EC 81) and detector off (EC 82) events and their timestamps are mapped for detection type ID 6. Along with the timestamp when the activation is occurring, the chart also displays the detector channel number (ch), movement type (L, T, R, TR or TL), and lane number.

Step 5: Identify Lane-by-Lane Count Activations

During this step, stop bar presence activations are identified. Detector on (EC 82) and detector off (EC 81) events and their timestamps are mapped for detection type ID 4. Along with the timestamp when the activation is occurring, the chart also displays the detector channel number (ch), movement type (L, T, R, TR or TL), and lane number.

Step 6: Identify Advanced Presence Activations

During this step, stop bar presence activations are identified. Detector on (EC 82) and detector off (EC 81) events and their timestamps are mapped for detection type ID 7. Along with the timestamp when the activation is occurring, the chart also displays the detector channel number (ch), movement type (L, T, R, TR or TL), and lane number and the detector setback (in feet).

Step 7: Identify Advanced Count Activations

During this step, stop bar presence activations are identified. Detector on (EC 82) and detector off (EC 81) events and their timestamps are mapped for detection type ID 2. Along with the timestamp when the activation is occurring, the chart also displays the detector channel number (ch), movement type (L, T, R, TR or TL), and lane number and the detector setback (in feet).

Step 8: Combine Detector Events for Phases

In this step, all the detector events for each lane category are combined together into one event per category. Detector events are listed in Exhibit 25.

Step 9: Display Raw Data

This metric has the option to display raw data and their time stamps based on user defined event codes (EC).

Step 10: Extend Search (left)

This is a user specified period of time (5 minute default) for signal event data behind the specified start time.

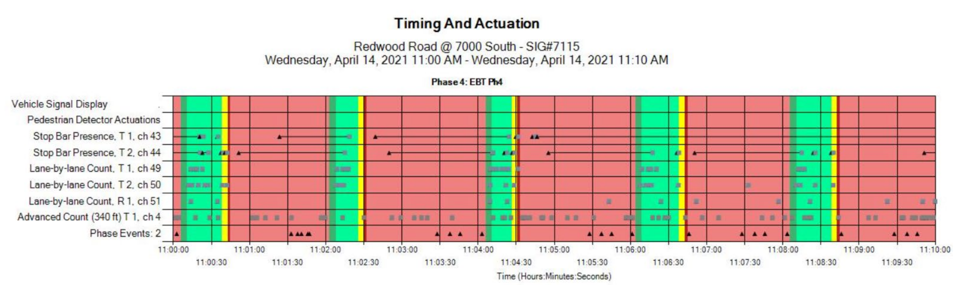
Step 11: Extend Start/Stop Search

This value will look back and forward a user specified period of time (2 minutes default) for vehicle and pedestrian detection actuations.

EXAMPLE

An example timing and actuation graph is shown in Exhibit 27. This is one of six charts for signal# 7115 since that intersection has six phases. Only the default options are shown for this example.

Exhibit 27 Example Timing and Actuation Diagram



14. LEFT TURN GAP ANALYSIS

OVERVIEW

Left turn movements without a protected phase must be made during gaps present in the opposing traffic. The left turn gap analysis measure quantifies the number of gaps by size and graphs them over time. The results of the measure can help identify locations that have a lack of sufficiently large gaps in traffic for drivers to make safe left turns.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the left turn gap analysis measure. The data are listed in Exhibit 28.

Exhibit 28 Required Input Data for Left Turn Gap Analysis Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 1 – Phase Begin Green EC 10 – Phase Begin Red Clear	
Detector Activation*	EC 81 – Detector Off	
Approach ID	Field [ApproachID] in Approaches Table	
Detector ID	Field [DetectorID] in Detector Table	Used to join tables to High-Resolution data
Detector Type	Field [DetectionTypeID] in Detection Type Table	Type 4 preferred; Type 6 may be used if Type 4 is absent
Lane Type	Event Parameter	Must be type 1, 2, 4, or 5

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

This measure determines the number of gaps within user-defined duration thresholds and the percent of the green time made up of large gaps (another user-defined threshold).

The calculation framework for left turn gap analysis is:

1. Identify each opposing phase
2. Tally the number of gaps in each cycle by duration
3. Calculate the percent of time in each cycle made up of large gaps
4. Sum the number of gaps by duration for each 15-minute period
5. Average the percent of time made up of large gaps for each 15-minute period

COMPUTATIONAL STEPS

Step 1: Identify Each Opposing Through Phase

During this step, the opposing through phase of each approach is identified. Charts will only be made for an approach if the opposing approach exists (e.g., the southbound chart will only be created if a northbound leg exists). For the protected through phase 2, the opposing phase is 6, and vice versa. For the protected through phase 4, the opposing phase is 8, and vice versa.

Step 2: Tally the Number of Gaps in Each Cycle by Duration

During this step, the duration of each gap is calculated, and the number of gaps within three duration bins are counted. The event log is queried to find the timestamps of the start of green interval (EC 1), the detector event (EC 81), and the start of red (EC 10). The detector event (EC 81) must have occurred in lane type 1 (through), 2 (right), 4 (through-right), or 5 (through-left). All the events are sorted by time order, and the duration of each gap is equal to the time difference between an event timestamp and the previous event timestamp.

Equation 76

$$g_i = t_i - t_{i-1}$$

Where:

i = integer ranging from 1 to n

g_i = duration in seconds of gap i

t_i = timestamp of event i

t_{i-1} = timestamp of event i - 1

t_0 = timestamp of the start of green interval (EC 1)

t_1 = timestamp of the first detector event (EC 81)

t_n = timestamp of the start of red (EC 10)

There are four user-defined gap duration bins, the default values of which are: 1 - 3.3 sec, 3.3 - 3.7 sec, 3.7 - 7.4 sec, and > 7.4 sec (lower thresholds are exclusive, upper thresholds are inclusive). When the duration of a gap is calculated, a value of 1 is added to the count for the respective gap duration bin.

Step 3: Calculate the Percent of Time in Each Cycle Consisting of Large Gaps

During this step, the percentage of time in each cycle consisting of large gaps is calculated. The sum of all gap durations greater than or equal to the user-defined trendline threshold (default: 7.4 sec) is divided by the duration of the green and yellow phases.

Equation 77

$$p_{c,l} = \frac{\sum g_{i*}}{t_g - t_r}$$

Where:

$p_{c,l}$ = percent of the time in each cycle made up of large gaps

g_{i*} = duration in seconds of gap i if greater than or equal to the trendline threshold (default: 7.4)

t_g = timestamp for begin of green interval (event code 1) during cycle C

t_r = timestamp for start of red clearance interval (event code 10) during cycle C

Step 4: Sum the Number of Gaps by Duration for Each 15-Minute Period

In this step, the number of gaps belonging to each user-defined gap duration bin is summed over a 15-minute period. All gaps in a cycle that begins during a 15-minute period are included in that 15-minute period sum.

Step 5: Average the Percent of Time Consisting of Large Gaps for Each 15-Minute Period

In this step, the average percentage of time consisting of large gaps in each 15-minute period is calculated. All values corresponding to a cycle that begins during a 15-minute period are included in that 15-minute period sum.

$$P_{15,l} = \frac{\sum p_{c,l}}{|p_{c,l}|} \times 100\%$$

Equation 78

Where:

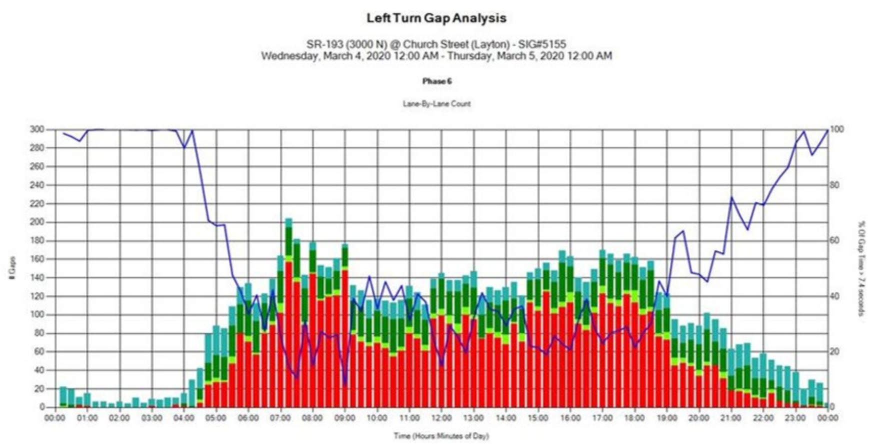
$p_{c,l}$ = percent of the time in each cycle made up of large gaps

$P_{15,l}$ = Percent of time in each 15-minute period made up of large gaps

EXAMPLE

An example left turn gap analysis graph is shown in Exhibit 29. This is one of four charts for this signal since this intersection has four approaches. The number of gaps 1 - 3.3 seconds long are shown in red, and the number of gaps > 7.4 seconds are shown in light blue. The blue line on the graph displays the percent of green and yellow time consisting of gaps greater than or equal to a threshold of 7.4 seconds.

Exhibit 29 Example Left Turn Gap Analysis Diagram



15. WAIT TIME

OVERVIEW

Wait time data can be useful for evaluating signal timing progression. The Wait Time measure quantifies the maximum wait time experienced by each movement for each cycle based on the phase call registered and phase call dropped event codes triggered by the presence detectors located at the intersection.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the wait time measure. The data are listed in Exhibit 30.

Exhibit 30 Required Input Data for Wait Time Measure

Required Data and Units	Source Data	Notes
Phase Interval Changes*	EC 1 – Phase Begin Green EC 4 – Phase Gap Out EC 5 – Phase Max Out EC 6 – Phase Force Off EC 11 – Phase End Red Clear EC 43 – Phase Call Registered EC 44 – Phase Call Dropped	
Phase	Event Parameter	Must be provided
Detector Type	Field [DetectionTypeID] in Detection Type Table	Type 2 and/or Type 6
Programmed Splits*	EC 134 thru 149 – Split Change	

Notes: EC = Event Code
*All data for EC code are stored in controller event log table

OVERVIEW OF THE METHODOLOGY

The wait time measure determines the longest vehicle wait time occurring for each phase at a signal. The computation framework is as follows for each phase at a signal:

1. Determine Phase Call Detection Types
2. Identify Phase Events
3. Identify Cycle Events
4. Determine Beginning of Wait Event
5. Calculate Wait Time
6. Determine Termination Type
7. Calculate Average Wait Time
8. Determine Programmed Splits
9. Determine Volume per Hour

COMPUTATIONAL STEPS

Step 1: Determine Phase Call Detection Types

During this step, the type(s) of phase call detection must be determined. For the measure to work, the phase must have detection Type 2 – Stop Bar Presence Detection or detection Type 6 – Advance Presence Detection. The presence of detection type 2 has influence on the method for calculating wait time as is described in step 4.

Step 2: Identify Phase Events

During this step, phase events are identified and sorted chronologically into 3 lists:

- EC 11 – Phase End Red Clear
- EC 1 – Phase Begin Green
- EC 43 – Phase Call Registered and EC 44 – Phase Call Dropped

Step 3: Identify Cycle Events

During this step, the phase event timestamps are matched to create pairs. A pair consists of the timestamp for a phase end red clear event (EC 11) and the timestamp of the following phase begin green event (EC 1).

Step 4: Determine Beginning of Wait Event

For each cycle event pair identified in Step 2, a list of the phase call registered (EC 43) and phase call dropped (EC 44) events that occurred between the paired events is created. The events in this list are ordered chronologically. The "Begin Wait Event" (BWE) is determined following the logic chart as shown in Exhibit 31:

- If stop bar presence detectors are not present for the phase *(Check 1 = No)*, then the BWE is the first EC 43 in the list of EC 43s and EC 44s *(Outcome 1)*.
- If stop bar detection is present for the phase *(Check 1 = Yes)*, then the last EC 44 in the list is identified.
    - If the last EC 44 is not the last record in the list *(Check 2 = No)*, then the BWE is the event (an EC 43) immediately following the last EC 44 in the list *(Outcome 2)*.
    - If it is the last record in the list, then there is no wait time, and the analysis moves onto the next cycle *(Outcome 3)*.

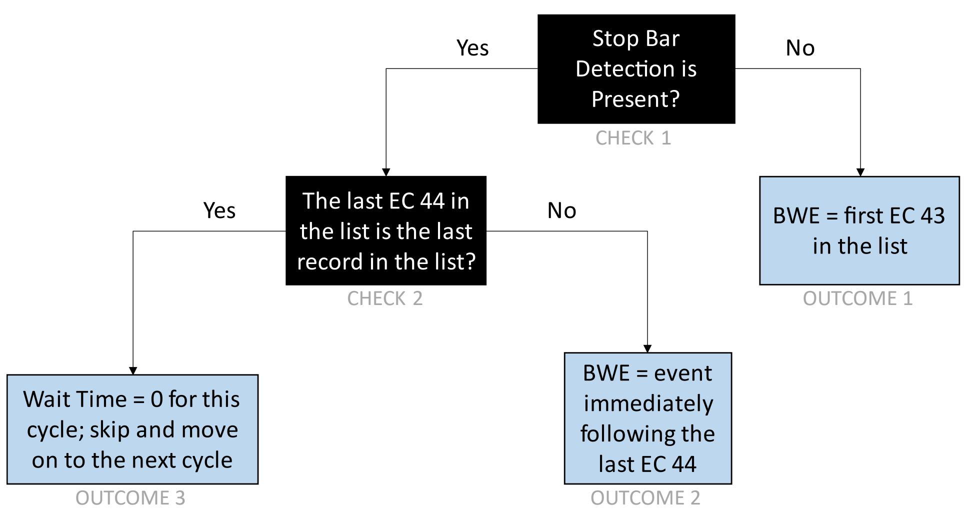


Exhibit 31 Logic Chart for Beginning of Wait Event

Step 5: Calculate Wait Time

The wait time is defined as the difference for the BWE and the next begin of green for each phase cycle and is calculated as: the timestamp of the following phase begin of green event (EC 1) minus the timestamp of the BWE as shown in Equation 79.

Equation 79

$$WaitTime = t_{green} - t_{BWE}$$

Where:

t_{green} is the timestamp of the following phase begin green event (EC 1)

t_{BWE} is the timestamp of the "Begin Wait Event" (EC 43) determined in Step 3

Any wait times greater than a 360-second threshold are removed due to the probability that wait time durations exceeding the threshold are miscalculations due to missing data.

Step 6: Determine Termination Type

Next, the phase termination type for each phase cycle is determined. That termination type is linked to that individual wait time by phase cycle and is displayed in the chart output for the measure.

Step 7: Calculate Average Wait Time

Next, the average wait time for each 15-minute period (beginning at the start of the analysis period) is calculated as shown in Equation 80.

Equation 80

$$(AvgWaitTime)_{i,j} = \frac{\sum_i^j WaitTime}{|WaitTime|_i^j}$$

Where:

i is the beginning of a 15-minute period

j is the end of a 15-minute period

i, j represents a duration beginning at i and ending at j

Step 8: Determine Programmed Splits

In this step, the program uses the event codes (between EC 134 and EC 149) to step through each phase and records the event parameter as split duration. This split duration is the programmed split for different plans.

Step 9: Determine Volume per Hour

The volume for each interval (standardized to volume per hour) is calculated by summing the total number of vehicle actuations within each 15-minute period (beginning at the start of the analysis period). These volumes are standardized to the equivalent volume per hour by multiplying by 4. Details on requirements to calculate the volume per hour are explained in Exhibit 1 and process is described in Steps 1 and 2 of Chapter 1.

EXAMPLE

An example Wait Time graph is shown in Exhibit 32. This is one of six charts for this signal since this intersection has six phases. The calculated wait time durations are shown as points on the chart, color-coded by termination type. The pink line on the graph displays the average wait time for each 15-minute period. The blue line on the graph displays the volume per hour for the phase for each 15-minute period. The orange line on the graph shows the programmed split; for the phase in the example, the split was approximately 25 seconds during Plan 13. The detection type(s) available is listed above the graph (e.g., "Stop Bar Detection," "Advance + Stop Bar Detection"). The plan name, average wait time, and max wait time are displayed above the graph for each plan in the analysis period.

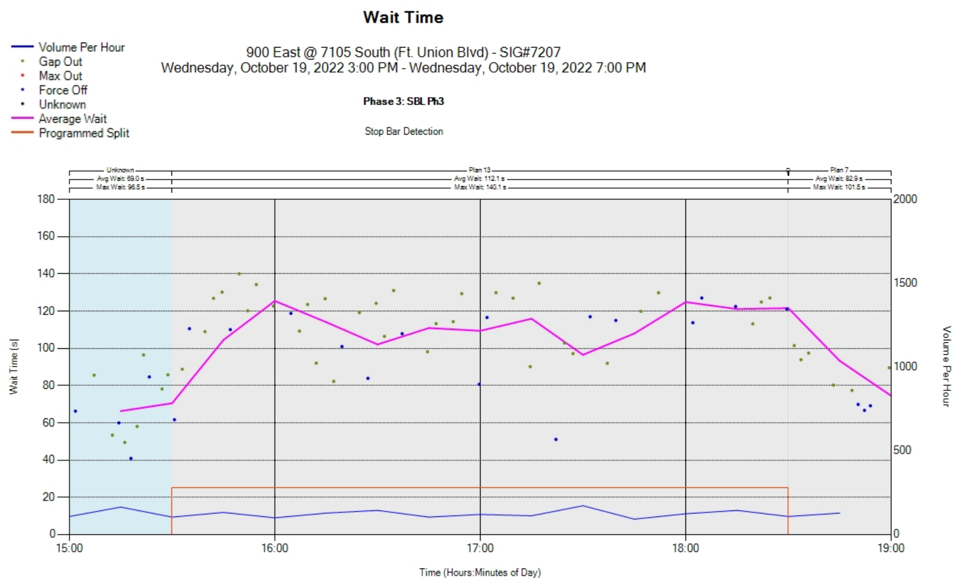


Exhibit 32 Example Wait Time Diagram

16. REFERENCES

1. Kittleson & Associates, Inc.; Purdue University; City of Portland; Iowa State University; and Kimley-Horn & Associates. *NCHRP Report 954: Performance-Based Management of Traffic Signals.* Transportation Research Board of the National Academies, Washington, DC, 2020. http://www.trb.org/Main/Blurbs/181009.aspx
2. Li, H., A.M. Hainen, J.R. Sturdevant, T. Atkinson, S. Talukder, J.K. Matthew, D.M. Bullock, D. Nelson, D.M. Maas, Jr., J. Fink, and T. Stiles. *Indiana Traffic Signal Hi Resolution Data Logger Enumerations.* Indiana Department of Transportation and Purdue University, West Lafayette, IN, 2019. https://docs.lib.purdue.edu/jtrpdata/4/
3. Sturdevant, J.R., T. Overman, E. Raamot, R. Deer, D. Miller, D.M. Bullock, C.M. Day, T.M. Brennan, H. Li, A. Hainen, and S.M. Remias. *Indiana Traffic Signal Hi Resolution Data Logger Enumerations.* Indiana Department of Transportation and Purdue University, West Lafayette, IN, 2012. https://docs.lib.purdue.edu/jtrpdata/3/
4. *National Transportation Communications for ITS Protocol (NTCIP) Object Definitions for Actuated Signal Controllers (ASC) Interface, NTCIP 1202 v03A*. American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and national Electrical Manufacturers Association (NEMA), Washington, DC, 2019. https://www.ntcip.org/wp-content/uploads/2019/07/NTCIP-1202v0328A.pdf
5. Day, C.M., D.M. Bullock, H. Li, S.M. Remias, A.M. Hainen, R.S. Freije, A.L. Stevens, J.R. Sturdevant, and T.M. Brennan. *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach.* Purdue University, West Lafayette, IN, 2014. https://docs.lib.purdue.edu/jtrpaffdocs/3/
6. Seegmiller, L., and Naylor, C. *Automated Traffic Signal Performance Measures User Case Examples,* 2020. Retrieved from https://udottraffic.utah.gov/ATSPM/Images/ATSPM_User%20Case%20Examples_Manual_20200128.pdf