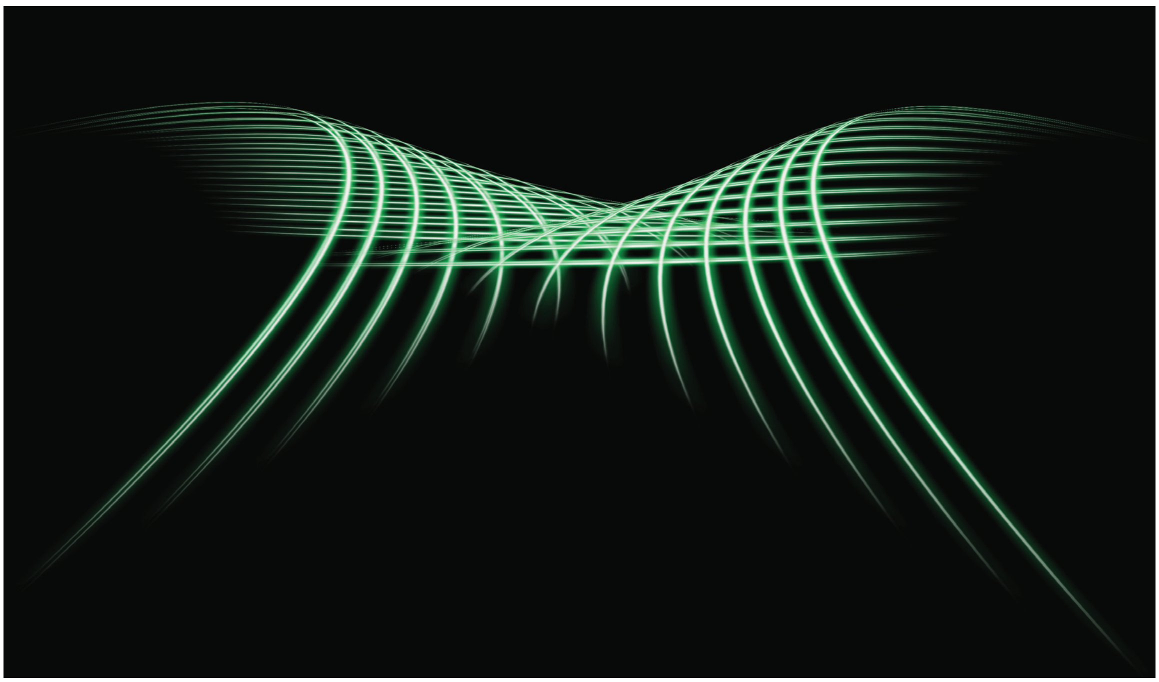
HCM2010

HIGHWAY CAPACITY MANUAL



CHAPTER 30

URBAN STREET SEGMENTS: SUPPLEMENTAL

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HCM2010

HIGHWAY CAPACITY MANUAL

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CHAPTER 30
URBAN STREET SEGMENTS: SUPPLEMENTAL

CONTENTS

LIST OF EXHIBITS

1. TRAFFIC DEMAND ADJUSTMENTS

This section describes adjustments made to the input vehicular demand flow rates at signalized boundary intersections such that they reasonably reflect actual operating conditions during the analysis period. These adjustments have no effect if existing vehicular flow rates are accurately quantified for the subject segment and all movements operate below their capacity. However, if the demand flow rate for one or more movements exceeds its capacity, or if there is disagreement between the count of vehicles entering and the count exiting the segment, then some movement flow rates will need to be adjusted to evaluate segment operation accurately.

This section describes three procedures that check the input flow rates and make adjustments if necessary. These procedures are

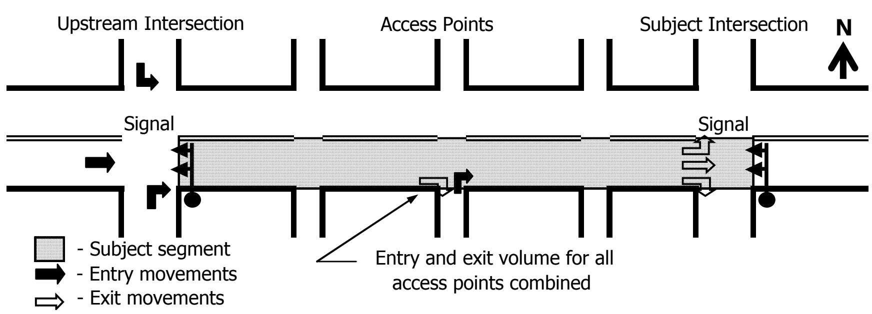
- Capacity constraint and volume balance,
- Origin–destination distribution, and
- Spillback check.

These procedures can be extended to the analysis of unsignalized boundary intersections; however, the mechanics of this extension are not described.

CAPACITY CONSTRAINT AND VOLUME BALANCE

This subsection describes the procedure for determining the turn movement flow rates at each intersection along the subject urban street segment. The analysis is separately applied to each travel direction and proceeds in the direction of travel. The procedure consists of a series of steps that are completed in sequence for the "entry" and "exit" movements associated with each segment. These movements are shown in Exhibit 30-1.

Exhibit 30-1
Entry and Exit Movements on the Typical Street Segment



As indicated in Exhibit 30-1, there are three entry movements associated with the upstream signalized intersection and three exit movements associated with the downstream signalized intersection. Entry and exit movements also exist at each access point intersection. However, these movements are aggregated into one entry and one exit movement for simplicity.

The analysis procedure is described in the following steps. Frequent reference is made to "volume" in these steps. In this application, volume is considered to be equivalent to average flow rate for the analysis period and to have units of vehicles per hour (veh/h).

Step 1: Identify Entry and Exit Volumes

Identified during this step is the volume for each entry and exit movement. The volume entering the segment from each access point intersection should be identified and added to obtain a total for the segment. Similarly, the volume exiting the segment from each access point intersection should be identified and added for the segment.

A maximum of four entry volumes are identified in this step. They include the left-turn, through, and right-turn movements at the upstream boundary intersection that enter the segment, plus the total access point entry volume. Similarly, a maximum of four exit volumes are identified. They include the left-turn, through, and right-turn movements at the downstream boundary intersection that exit the segment, plus the total access point exit volume.

Step 2: Estimate Movement Capacity

During this step, the capacity of each signalized entry movement is estimated. This estimate should be a reasonable approximation based on estimates of the saturation flow rate for the corresponding movement and the phase splits established for signal coordination.

If the right-turn movement at the upstream intersection shares a lane with its adjacent through movement, then the discharge flow rate for the turn movement can be estimated by using Equation 30-1.

Equation 30-1

$$s_{q|r} = s_{sr} \ P_R$$

where

$s_{q|r}$ = shared lane discharge flow rate for upstream right-turn traffic movement in vehicles per hour per lane (veh/h/ln),

s_{sr} = saturation flow rate in shared right-turn and through-lane group with permitted operation (veh/h/ln), and

P_R = proportion of right-turning vehicles in the shared lane (decimal).

The procedure described in Chapter 18, Signalized Intersections, is used to estimate the two variables shown in Equation 30-1. A similar equation can be constructed to estimate the shared lane discharge flow rate for an upstream left-turn movement in a shared lane.

The capacity for the right-turn movement in the shared-lane lane group is then computed by using Equation 30-2.

Equation 30-2

$$c_{q|r} = s_{q|r} \ g / C$$

where

$c_{q|r}$ = shared lane capacity for upstream right-turn traffic movement (veh/h),

$s_{q|r}$ = shared lane discharge flow rate for upstream right-turn traffic movement (veh/h/ln),

g = effective green time (s), and

C = cycle length (s).

The procedure described in Chapter 18 is used to estimate the signal timing variables shown in Equation 30-2. A similar equation can be constructed for an upstream left-turn movement in a shared lane.

Step 3: Compute Volume-to-Capacity Ratio

During this step, the volume-to-capacity ratio is computed for each signalized entry movement. This ratio is computed by dividing the arrival volume from Step 1 by the capacity estimated in Step 2. Any movements with a volume-to-capacity ratio in excess of 1.0 will meter the volume arriving to the downstream intersection.

Step 4: Compute Discharge Volume

The discharge volume from each of the three signalized entry movements is equal to the smaller of its entry volume or its associated movement capacity. The total discharge volume for the combined access point approach is assumed to be equal to the total access point entry volume. As a last calculation, the four discharge volumes are added to obtain the total discharge volume.

Step 5: Compute Adjusted Exit Volume

The total discharge volume from Step 4 should be compared with the total exit volume. The total exit volume represents the sum of the four exit volumes identified in Step 1. If the two totals do not agree in magnitude, the four exit volumes must be adjusted such that their sum equals the total discharge volume. The adjusted exit volume for a movement equals its exit volume multiplied by the "volume ratio." The volume ratio equals the total discharge volume divided by the total exit volume.

Step 6: Repeat Steps 1 Through 5 for Each Segment

The preceding steps should be completed for each segment in the facility in the subject direction of travel. The procedure should then be repeated for the opposing direction of travel.

ORIGIN–DESTINATION DISTRIBUTION

The volume of traffic that arrives at a downstream intersection for a given downstream movement represents the combined volume from each upstream point of entry weighted by its percentage contribution to the downstream movement. The distribution of these contribution percentages between each upstream and downstream pair is represented as an origin–destination distribution matrix.

Ideally, an origin–destination survey would be conducted for an existing segment, or the origin–destination data would be available from traffic forecasts by planning models. One matrix would be available for each direction of travel on the segment. In the absence of such information, origin–destination volumes can be estimated from the entry and exit volumes for a segment, where the exit volumes equal the adjusted arrival volumes from the procedure described in the previous subsection, Capacity Constraint and Volume Balance.

Each of the four entry movements to the segment shown in Exhibit 30-1 is considered an origin. Each of the four exit movements is a destination. The problem then becomes one of estimating the origin–destination table given the entering and exiting volumes.

This procedure is derived from research (*1*). It is based on the principle that total entry volume is equal to total exit volume. It uses seed proportions to represent the best estimate of the volume distribution. These proportions are refined through implementation of the procedure. It is derived to estimate the most probable origin–destination volumes by minimizing the deviation from the seed percentages while ensuring the equivalence of entry and exit volumes.

The use of seed percentages allows the procedure to adapt the origin–destination volume estimates to factors or geometric situations that induce greater preference for some entry–exit combinations than is suggested by simple volume proportion (e.g., a downstream freeway on-ramp). The default seed proportions are listed in Exhibit 30-2.

Exhibit 30-2 Default Seed Proportions for Origin–Destination Matrix

Seed Proportion by Origin Movement				Destination Movement
Left	**Through**	**Right**	**Access Point**	
0.02	0.10	0.05	0.02	Left
0.91	0.78	0.92	0.97	Through
0.05	0.10	0.02	0.01	Right
0.02	0.02	0.01	0.00	Access point
1.00	1.00	1.00	1.00	

Step 1: Set Adjusted Origin Volume

Equation 30-3

$$O_{a,i} = O_i$$

where

$O_{a,i}$ = adjusted volume for origin i (i = 1, 2, 3, 4) (veh/h), and

O_i = volume for origin i (i = 1, 2, 3, 4) (veh/h).

The letter i denotes the four movements entering the segment. This volume is computed for each of the four origins.

Step 2: Compute Adjusted Destination Volume

Equation 30-4

$$D_{a,j} = \sum_{i=1}^{4} O_{a,i}\ p_{i,j}$$

where

$D_{a,j}$ = adjusted volume for destination j (j = 1, 2, 3, 4) (veh/h),

$O_{a,i}$ = adjusted volume for origin i (i = 1, 2, 3, 4) (veh/h), and

$p_{i,j}$ = seed proportion of volume from origin i to destination j (decimal).

The letter j denotes the four movements exiting the segment. This volume is computed for each of the four destinations.

Step 3: Compute Destination Adjustment Factor

$$b_{d,j} = \frac{D_j}{D_{a,j}}$$

Equation 30-5

where

$b_{d,j}$ = destination adjustment factor j (j = 1, 2, 3, 4),

D_j = volume for destination j (j = 1, 2, 3, 4) (veh/h), and

$D_{a,j}$ = adjusted volume for destination j (j = 1, 2, 3, 4) (veh/h).

This factor is computed for each of the four destinations.

Step 4: Compute Origin Adjustment Factor

$$b_{o,i} = \sum_{j=1}^{4} b_{d,j}\ p_{i,j}$$

Equation 30-6

where $b_{o,i}$ is the origin adjustment factor i (i = 1, 2, 3, 4), and other variables are as previously defined. This factor is computed for each of the four origins.

Step 5: Compute Adjusted Origin Volume

$$O_{a,i} = \frac{O_i}{b_{o,i}}$$

Equation 30-7

where $O_{a,i}$ = adjusted volume for origin i (i = 1, 2, 3, 4) (veh/h), and other variables are as previously defined. This volume is computed for each of the four origins. It replaces the value previously determined for this variable.

For each origin, compute the absolute difference between the adjusted origin volume from Equation 30-7 and the previous estimate of the adjusted origin volume. If the sum of these four differences is less than 0.01, then proceed to Step 6; otherwise, set the adjusted origin volume for each origin equal to the value from Equation 30-7, go to Step 2, and repeat the calculation sequence.

Step 6: Compute Origin–Destination Volume

$$v_{i,j} = O_{a,i}\ b_{d,j}\ p_{i,j}$$

Equation 30-8

where $v_{i,j}$ is the volume entering from origin i and exiting at destination j (veh/h), and other variables are as previously defined. This volume is computed for all 16 origin–destination pairs.

SPILLBACK CHECK

This subsection describes the procedure for determining whether queue spillback occurs on one or more segments of an urban street facility. The analysis is separately applied to each travel direction and proceeds in the direction of travel. The procedure consists of a series of steps that are completed in sequence for the signalized exit movements associated with each segment. These movements are shown in Exhibit 30-1. Spillback due to the movements associated with the access points is not specifically addressed.

Step 1: Identify Initial Queue

During this step, the initial queue for each signalized exit movement is identified. This value represents the queue present at the start of the analysis period (the total of all vehicles in all lanes serving the movement). The initial queue estimate would likely be available for the evaluation of an existing condition for which field observations indicate the presence of a queue at the start of the analysis period. For planning or preliminary design applications, it can be assumed to equal 0.0 vehicles.

Step 2: Identify Queue Storage Length

The length of queue storage for each exit movement is identified during this step. For turn movements served from a turn bay, this length equals the length of the turn bay. For through movements, this length equals the segment length less the width of the upstream intersection. For turn movements served from a lane equal in length to that of the segment, the queue storage length equals the segment length less the width of the upstream intersection.

Step 3: Compute Maximum Queue Storage

The maximum queue storage for the exiting through movement is computed by using Equation 30-9.

Equation 30-9

$$N_{qx,thru} = \frac{(N_{th} - P_L - P_R)\ L_{a,thru}}{L_h}$$

with

Equation 30-10

$$L_h = L_{pc}(1 - 0.01\ P_{HV}) + 0.01\ L_{HV}\ P_{HV}$$

where

$N_{qx,thru}$ = maximum queue storage for the through movement (veh),

N_{th} = number of through lanes (shared or exclusive) (ln),

P_L = proportion of left-turning vehicles in the shared lane (decimal),

P_R = proportion of right-turning vehicles in the shared lane (decimal),

$L_{a,thru}$ = available queue storage distance for the through movement (ft/ln),

L_h = average vehicle spacing in stationary queue (ft/veh),

L_{pc} = stored passenger-car lane length = 25 (ft),

L_{HV} = stored heavy-vehicle lane length = 45 (ft), and

P_{HV} = percent heavy vehicles in the corresponding movement group (%).

The procedure described in Chapter 18, Signalized Intersections, is used to estimate P_L and P_R. If there are no shared lanes, then P_L = 0.0 and P_R = 0.0.

The maximum queue storage for a turn movement is computed by using Equation 30-11.

Equation 30-11

$$N_{qx,turn} = \frac{N_{turn}\ L_{a,turn} + P_{turn}\ L_{a,thru}}{L_h}$$

where

$N_{qx,turn}$ = maximum queue storage for a turn movement (veh),

N_{turn} = number of lanes in the turn bay (ln),

$L_{a,turn}$ = available queue storage distance for the turn movement (ft/ln),

P_{turn} = proportion of turning vehicles in the shared lane = P_L or P_R (decimal), and

L_h = average vehicle spacing in stationary queue (ft/veh).

This equation is applicable to turn movements in exclusive lanes (i.e., P_{turn} = 0.0) and to turn movements that share a through lane.

Step 4: Compute Available Storage Length

The available storage length is computed for each signalized exit movement by using Equation 30-12.

$$N_{qa} = N_{qx} - Q_b \quad \geq 0.0$$

Equation 30-12

where

N_{qa} = available queue storage (veh),

N_{qx} = maximum queue storage for the movement (veh), and

Q_b = initial queue at the start of the analysis period (veh).

The analysis thus far has treated the three signalized exit movements as if they were independent. At this point, the analysis must be extended to include the combined through and left-turn movement when the left-turn movement has a bay (i.e., it does not have a lane that extends the length of the segment). The analysis must also be extended to include the combined through and right-turn movement when the right-turn movement has a bay (but not a full-length lane).

The analysis of these newly formed "combined movements" is separated into two parts. The first part represents the analysis of just the bay. This analysis represents a continuation of the exit movement analysis using the subsequent steps of this procedure. The second part represents the analysis of the length of the segment shared by the turn movement and the adjacent through movement. The following rules are used to evaluate the combined movements for the shared segment length:

1. The volume for each combined movement equals the sum of the adjusted arrival volumes for the two contributing movements. These volumes are obtained from the procedure described in the previous subsection, Origin–Destination Distribution.
2. The initial queue for each combined movement is computed by using Equation 30-13.

$$Q_{b,comb} = \max\left(0.0, Q_{b,turn} - \frac{L_{a,turn}\ N_{turn}}{L_h}, Q_{b,thru} - \frac{L_{a,turn}\ N_{th}}{L_h}\right)$$

Equation 30-13

where $Q_{b,comb}$ equals the initial queue for the combined movement (veh). The other variables were defined previously and are evaluated for the movement indicated by the variable subscript.

3. The queue storage length for a combined movement $L_{a,comb}$ equals the queue storage length for the through movement less the queue storage length of the turn movement (i.e., $L_{a,comb} = L_{a,thru} - L_{a,turn}$).
4. The number of lanes available to the combined movement N_{comb} equals the number of lanes available to the through movement.
5. The maximum queue storage for the combined movement is computed by applying the guidance provided in Step 3 using the variables from Rules 3 and 4.
6. The available storage length for the combined movement $N_{qa,comb}$ is computed by using the guidance provided previously in this step for the exit movements.

Step 5: Compute Capacity

The capacity for both the exit movements and the combined movements is established in this step. The capacity for each exit movement was computed in Step 2 in the subsection titled Capacity Constraint and Volume Balance. The capacity of the combined movements is computed by using Equation 30-14.

Equation 30-14

$$c = \frac{v_{a,1}}{X_1} + \frac{c_{thru}\,(N_{th} - 1)}{N_{th}}$$

with

Equation 30-15

$$v_{a,1} = \max\left(v_{a,turn}, \frac{v_{a,turn} + v_{a,thru}}{N_{th}} \right)$$

Equation 30-16

$$X_1 = \frac{v_{a,turn}}{c_{turn}} + \frac{v_{a,1} - v_{a,turn}}{c_{thru} / N_{th}}$$

where

c = capacity of the combined movements (veh/h),

$v_{a,1}$ = adjusted arrival volume in the shared lane (veh/h),

X_1 = volume-to-capacity ratio in the shared lane,

c_{thru} = capacity for the exiting through movement (veh/h),

c_{turn} = capacity for the exiting turn movement (veh/h),

$v_{a,turn}$ = adjusted arrival volume for the subject turn movement (veh/h),

$v_{a,thru}$ = adjusted arrival volume for the subject through movement (veh/h), and

N_{th} = number of through lanes (shared or exclusive) (ln).

The two adjusted arrival volumes $v_{a,turn}$ and $v_{a,thru}$ are obtained from the procedure described in the subsection titled Origin–Destination Distribution.

Step 6: Compute Queue Growth Rate

During this step, the queue growth rate is computed for each signalized exit movement for which the storage extends the length of the segment. Typically, the through movement satisfies this requirement. A turn movement may also satisfy this requirement if it is served by an exclusive lane that extends the length of the segment. The queue growth rate is computed as the difference between the adjusted arrival volume v_a and the capacity c for the subject exit movement. Equation 30-17 is used to compute this rate.

$$r_{qg} = v_a - c \quad \geq 0.0$$

Equation 30-17

where r_{qg} is the queue growth rate (veh/h) and other variables are as defined previously.

The queue growth rate is also computed for the combined movements formulated in Step 4. The adjusted volume used in Equation 30-17 represents the sum of the through and turn movement volumes in the combined group. The capacity for the group was computed in Step 5.

Step 7: Compute Time Until Spillback

During this step, the time until spillback is computed for each signalized exit movement for which the storage extends the length of the segment. This time is computed by using Equation 30-18 for any movement with a nonzero queue growth rate.

$$T_c = \frac{N_{qa}}{r_{qg}}$$

Equation 30-18

where T_c is the time until spillback (h) and other variables are as defined previously.

For turn movements served by a bay, the computed spillback time represents the time required for the bay to overflow. It does not represent the time that the turn-related queue reaches the upstream intersection.

Equation 30-18 is also used to compute the spillback time for the combined movements formulated in Step 4. However, this spillback time represents the additional time required for the queue to grow along the length of segment shared by the turn movement and the adjacent through movement. This time must be added to the time required for the corresponding turn movement to overflow its bay to obtain the actual spillback time for the combined movement.

Step 8: Repeat Steps 1 Through 7 for Each Segment

The preceding steps should be completed for each segment in the facility in the subject direction of travel. The procedure should then be repeated for the opposing direction of travel.

Step 9: Determine Controlling Spillback Time

During this step, the shortest time until spillback for each of the exit movements (or movement groups) for each segment and direction of travel is identified. If the segment supports two travel directions, then two values are identified (one value for each direction). The shorter value of the two represents the controlling spillback time for the segment. If a movement (or movement group) does not spill back, it is not considered in this process for determining the controlling spillback time.

Next, the controlling segment times are compared for all segments that make up the facility. The shortest time found represents the controlling spillback time for the facility.

If the controlling spillback time exceeds the analysis period, then the results from the automobile methodology are considered to reflect the operation of the facility accurately. If spillback occurs before the end of the desired analysis period, then the analyst should consider either (*a*) reducing the analysis period such that it ends before spillback occurs or (*b*) using an alternative analysis tool that is able to model the effect of spillback conditions.

2. SIGNALIZED SEGMENT ANALYSIS

This section describes the process for analyzing vehicular traffic flow on a segment bounded by signalized intersections. Initially, this process computes the flow profile of discharging vehicles at the upstream intersection as influenced by the signal timing and phase sequence. It uses this profile to compute the arrival flow profile at a downstream junction. This arrival flow profile is then compared with the downstream signal timing and phase sequence to compute the proportion of vehicles arriving during green. The arrival flow profile is also used to compute the proportion of time that a platoon blocks one or more traffic movements at a downstream access point intersection. These two platoon descriptors are used in subsequent procedures to compute delay and other performance measures.

This section describes four procedures that are used to define the arrival flow profile and compute the related platoon descriptors. These procedures are

- Discharge flow profile,
- Running time,
- Projected arrival flow profile, and
- Proportion of time blocked.

Each procedure is described in the following subsections.

DISCHARGE FLOW PROFILE

A flow profile is a macroscopic representation of steady traffic flow conditions for the average signal cycle during the specified analysis period. The cycle is represented as a series of 1-s time intervals (hereafter referred to as "time steps"). The start time of the cycle is 0.0 s, relative to the system reference time. The time steps are numbered from 1 to C', where C' is the cycle length in units of time steps. The flow rate for step i represents an average of the flows that occur during the time period corresponding to step i for all cycles in the analysis period. This approach is conceptually the same as that used in the TRANSYT-7F model (*2*).

A discharge flow profile is computed for each of the upstream left-turn, through, and right-turn movements. Each profile is defined by the time that the signal is effectively green and by the time that the queue service time ends. During the queue service time, the discharge flow rate is equal to the saturation flow rate. After the queue service time is reached, the discharge rate is set equal to the "adjusted discharge volume." The adjusted discharge volume is equal to the discharge volume computed by using the procedures described in Section 1, but it is adjusted to reflect the "proportion of arrivals during green." This latter adjustment adapts the discharge flow pattern to reflect platoon arrivals on the upstream segment.

The discharge flow profile is dependent on movement saturation flow rate, queue service time, phase duration, and proportion of arrivals during green for the discharging movements. The movement saturation flow rate is computed by using a procedure described in Section 1. Procedures for calculating the remaining variables are described in subsequent subsections. This relationship introduces a circularity in the computations that requires an iterative sequence of calculations to converge on the steady-state solution.

RUNNING TIME

The running time procedure describes the calculation of running time between the upstream intersection and a downstream intersection. This procedure is described as Step 2 of the automobile methodology in Chapter 17, Urban Street Segments.

One component of running time is the delay due to various midsegment sources. One notable source of delay is left or right turns from the segment at an access point intersection. This delay is computed by using the procedure described in Section 3. Other sources of delay include on-street parking maneuvers and pedestrian crosswalks. Delay from these sources represents an input variable to the methodology.

PROJECTED ARRIVAL FLOW PROFILE

This subsection describes the procedure for predicting the arrival flow profile at a downstream intersection (i.e., access point or boundary intersection). This flow profile is based on the discharge flow profile and running time computed previously. The discharge flow profile is used with a platoon dispersion model to compute the arrival flow profile. The platoon dispersion model is summarized in the next part of this subsection. The procedure for using this model to estimate the arrival flow profile is described in the second part.

Platoon Dispersion Model

The platoon dispersion model was originally developed for use in the TRANSYT model (*3*). Input to the model is the discharge flow profile for a specified traffic movement. Output statistics from the model include (*a*) the arrival time of the leading vehicles in the platoon to a specified downstream intersection and (*b*) the flow rate during each subsequent time step.

In general, the arrival flow profile has a lower peak flow rate than the discharge flow profile owing to the dispersion of the platoon as it travels down the street. Also, for similar reasons, the arrival flow profile is spread out over a longer period of time than the discharge flow profile. The rate of dispersion increases with increasing segment running time, which may be caused by access point activity, on-street parking maneuvers, and other midsegment delay sources.

The platoon dispersion model is described by Equation 30-19.

Equation 30-19

$$q'_{a|u,j} = F\, q'_{u,i} + (1 - F)\, q'_{a|u,j-1}$$

with

Equation 30-20

$$j = i + t'$$

where

$q'_{a|u,j}$ = arrival flow rate in time step j at a downstream intersection from upstream source u (veh/step),

$q'_{u,i}$ = departure flow rate in time step i at upstream source u (veh/step),

F = smoothing factor,

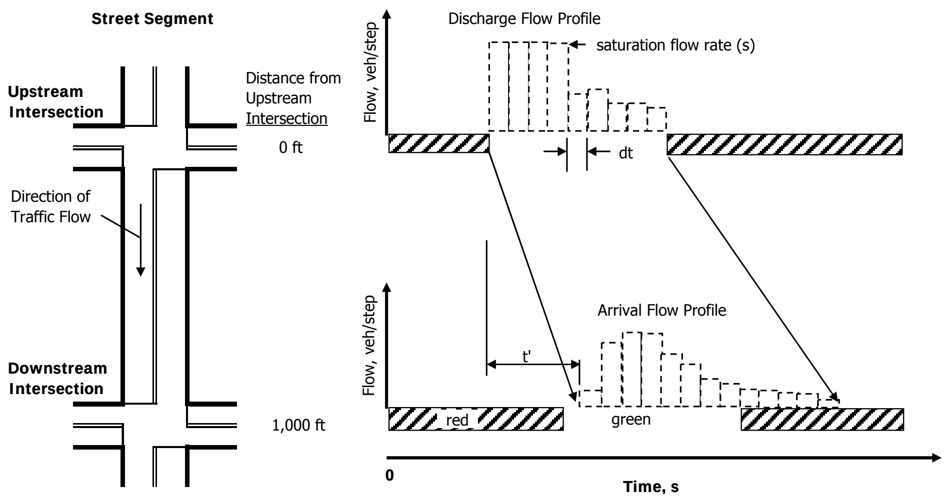
j = time step associated with platoon arrival time t', and

t' = platoon arrival time (steps).

The upstream flow source u can be either the left-turn, through, or right-turn movement at the upstream boundary intersection. It can also be the collective set of left-turn or right-turn movements at access point intersections between the upstream boundary intersection and the subject intersection.

Exhibit 30-3 illustrates an arrival flow profile obtained from Equation 30-19. In this figure, the discharge flow profile is input to the model as variable $q'_{u,i}$. The dashed rectangles that form the discharge flow profile indicate the flow rate during each of nine time steps (i = 1, 2, 3, . . . , 9) that are each d_t seconds in duration. The vehicles that depart in the first time step (i = 1) arrive at the downstream intersection after traveling an amount of time equal to t' steps. The arrival flow at any time step j (= $i + t'$) is computed by using Equation 30-19.

Exhibit 30-3
Platoon Dispersion Model



Research (*4*) indicates that Equation 30-21 describes the relationship between the smoothing factor and running time.

Equation 30-21

$$F = \frac{1}{1 + 0.138\, t'_R + 0.315 / d_t}$$

where

t'_R = segment running time = t_R/d_t (steps),

t_R = segment running time (s), and

d_t = time step duration (s/step).

The recommended time step duration for this procedure is 1.0 s/step. Shorter values can be rationalized to provide a more accurate representation of the profile, but they also increase the time required for the computations. Experience indicates that 1.0 s/step provides a good balance between accuracy and computation time.

Equation 30-22 is used to compute platoon arrival time to the subject downstream intersection.

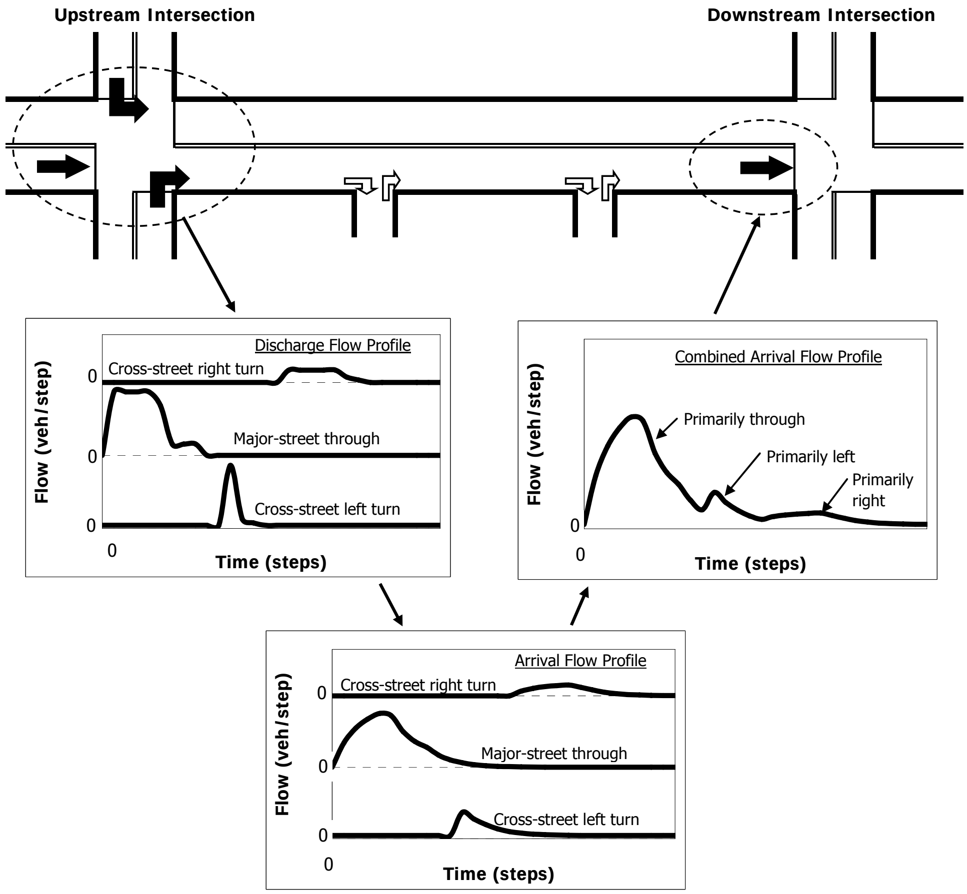
Equation 30-22

$$t' = t'_R - \frac{1}{F} + 1.25$$

Arrival Flow Profile

This part describes the procedure for computing the arrival flow profile. Typically, there are three upstream traffic movements that depart at different times during the signal cycle; they are the minor-street right turn, major-street through, and minor-street left turn. Traffic may also enter the segment at various midblock access points. Exhibit 30-4 illustrates how these movements join to form the arrival flow profile for the subject downstream intersection.

Exhibit 30-4
Arrival Flow Profile Estimation Procedure



In application, the discharge flow profile for each of the departing movements is obtained from the discharge flow profile procedure described previously. These profiles are shown in the first of the three *x*-*y* plots in Exhibit 30-4. The platoon dispersion model is then used to estimate the arrival flows for each movement at a downstream intersection. These arrival flow profiles are shown in the second *x*-*y* plot in the exhibit. Although not shown, arrivals from midsegment access points are assumed to have a uniform arrival flow profile (i.e., a constant flow rate for all time steps).

Finally, the origin–destination distribution procedure is used to distribute each arrival flow profile to each of the downstream exit movements. The four arrival flow profiles associated with the subject exit movement are added together to produce the combined arrival flow profile. This profile is shown in the third *x-y* plot. The upstream movement contributions to this profile are indicated by arrows.

Comparison of the profiles in the first and second *x-y* plots of Exhibit 30-4 illustrates the platoon dispersion process. In the first *x-y* plot, the major-street through movement has formed a dense platoon as it departs the upstream intersection. However, by the time this platoon reaches the downstream intersection it has spread out and has a lower peak flow rate. In general, the amount of platoon dispersion increases with increasing segment length. For very long segments, the platoon structure degrades and arrivals become uniform throughout the cycle.

Platoon structure can also degrade as a result of significant access point activity along the segment. Streets with frequent active access point intersections tend to have more vehicles leave the platoon (i.e., turn from the segment at an access point) and enter the segment after the platoon passes (i.e., turn in to the segment at an access point). Both activities result in significant platoon decay.

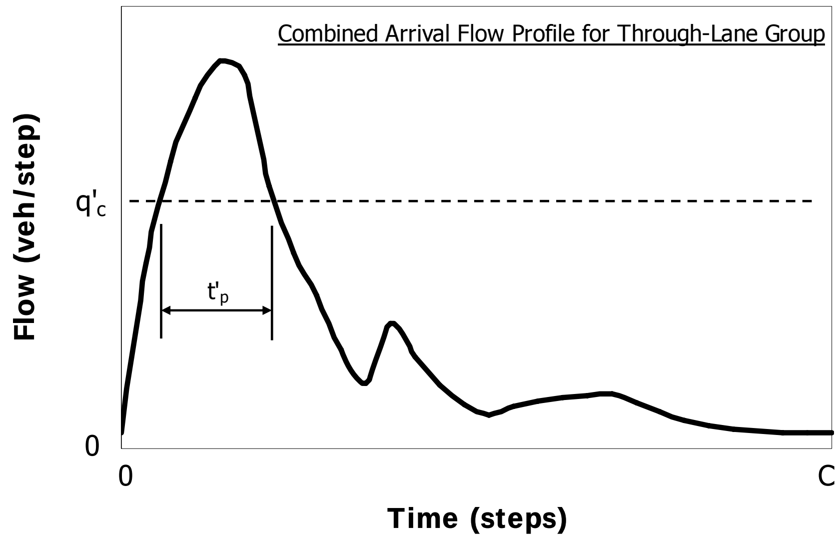
The effect of platoon decay is modeled by using the origin–destination matrix, in which the combined access point activity is represented as one volume assigned to midsegment origins and destinations. When the access point volume is large, it corresponds to a smaller volume that enters at the upstream boundary intersection as a defined platoon. This results in a larger portion of the combined arrival flow profile defined by uniform (rather than platoon) arrivals. When a street has busy access points, platoon decay tends to be a more dominant cause of platoon degradation than platoon dispersion.

PROPORTION OF TIME BLOCKED

The combined arrival flow profile can be used to estimate the time that a platoon passes through a downstream access point intersection. During this time period, the platoon can be sufficiently dense as to preclude a minor movement driver from finding an acceptable gap.

The use of the arrival flow profile to estimate the blocked period duration is shown in Exhibit 30-5. The profile shown represents the combined arrival flow profile for the through-lane group at a downstream access point intersection. The dashed line represents the critical platoon flow rate. Flow rates in excess of this threshold are rationalized to be associated with platoon headways that are too short to be entered (or crossed) by minor movements. The critical platoon flow rate q_c is equal to the inverse of the critical headway t_c associated with the minor movement (i.e., $q_c = 3{,}600/t_c$). The appropriate critical headway values for various movements are identified in Chapter 19, Two-Way STOP-Controlled Intersections.

Exhibit 30-5
Estimation of Blocked Period Duration



In the situation of a driver desiring to complete a left turn from the major street across the traffic stream represented by Exhibit 30-5, the proportion of time blocked is computed by using Equation 30-23. For this maneuver, the blocked period duration is based on the flow profile of the opposing through-lane group.

Equation 30-23

$$p_b = \frac{t'_p \, d_t}{C}$$

where

p_b = proportion of time blocked (decimal),

t'_p = blocked period duration (steps),

d_t = time step duration (s/step), and

C = cycle length (s).

Equation 30-23 is also used for the minor-street right-turn movement. However, in this situation, the blocked period duration is computed for the through-lane group approaching from the left. For the minor-street left-turn and through movements, the arrival flow profiles from both directions are evaluated. In this instance, the blocked period duration represents the time when a platoon from either direction is present in the intersection.

3. DELAY DUE TO TURNS

This section describes a process for estimating the delay to through vehicles that follow vehicles turning from the major street into an unsignalized access point intersection. This delay can be incurred at any access point intersection along the street. For right-turn vehicles, the delay results when the following vehicles' speed is reduced to accommodate the turning vehicle. For left-turn vehicles, the delay results when the following vehicles must wait in queue while a vehicle ahead executes a left-turn maneuver at the access point. This delay occurs primarily on undivided streets; however, it can also occur on divided streets when the left-turn queue exceeds the available storage and spills back into the inside through lane.

The delay estimation process consists of the following two procedures:

- Delay due to left turns, and
- Delay due to right turns.

Each procedure is described in the following subsections. These procedures are based on the assumption that the segment traffic flows are random. While this assumption may not be strictly correct for urban streets, it is conservative in that it will yield slightly larger estimates of delay. Moreover, expansion of the models to accommodate platooned flows would not likely be cost-effective given the small amount of delay caused by turning vehicles.

DELAY DUE TO LEFT TURNS

Through vehicles on the major-street approach to an unsignalized intersection can incur delay when the left-turn queue exceeds the available storage and blocks the adjacent through lane (in this context, the undivided cross section is considered a major-street approach having no left-turn storage). The through vehicles that follow are delayed when they stop behind the queue of turning vehicles. This delay ends when the left-turn vehicle departs or the through vehicle merges into the adjacent through lane. By merging into the adjacent lane, drivers reduce their delay relative to the delay they would have incurred had they waited for the left-turn queue to clear. This delay is computed by using Equation 30-24.

$$d_{ap,l} = p_{ov}\ d_{t,1}\left(\frac{1}{P_L} - 1\right)\frac{P_{lt}}{1 - P_{lt} - P_{rt}}$$

Equation 30-24

where

$d_{ap,l}$ = through vehicle delay due to left turns (s/veh),

p_{ov} = probability of left-turn bay overflow (decimal),

$d_{t,1}$ = average delay to through vehicles in the inside lane (s/veh),

P_L = proportion of left-turning vehicles in the shared lane (decimal),

P_{rt} = proportion of right-turning vehicles on the subject approach (decimal), and

P_{lt} = proportion of left-turning vehicles on the subject approach (decimal).

As indicated by Equation 30-24, the delay due to left turns is based on the value of several variables. The following sequence of computations can be used to estimate these values (*5*).

Step 1: Compute the Probability of a Lane Change

Equation 30-25

$$P_{lc} = 1 - \left(\left[2 \frac{v_{app}}{s_{lc}} \right] - 1 \right)^2 \quad \geq 0.0$$

with

Equation 30-26

$$v_{app} = \frac{v_{lt} + v_{th} + v_{rt}}{N_{sl} + N_t + N_{sr}}$$

where

P_{lc} = probability of a lane change among the approach through lanes,

v_{app} = average demand flow rate per through lane (upstream of any turn bays on the approach) (veh/h/ln),

s_{lc} = maximum flow rate in which a lane change can occur = 3,600/t_{lc} (veh/h/ln),

t_{lc} = critical merge headway = 3.7 (s),

v_{lt} = left-turn demand flow rate (veh/h),

v_{th} = through demand flow rate (veh/h),

v_{rt} = right-turn demand flow rate (veh/h),

N_{sl} = number of lanes in shared left-turn and through-lane group (ln),

N_t = number of lanes in exclusive through-lane group (ln), and

N_{sr} = number of lanes in shared right-turn and through-lane group (ln).

If the ratio v_{app}/s_{lc} in Equation 30-25 exceeds 1.0, then it should be set to 1.0.

Step 2: Compute Through Vehicle Equivalent for Left-Turn Vehicle

Equation 30-27

$$E_{L1} = \frac{1{,}800}{c_l}$$

with

Equation 30-28

$$c_l = \frac{v_o\, e^{-v_o\, t_{cg} / 3{,}600}}{1 - e^{-v_o\, t_{fh} / 3{,}600}}$$

where

E_{L1} = equivalent number of through cars for a permitted left-turning vehicle;

c_l = capacity of a left-turn movement with permitted left-turn operation (veh/h);

v_o = opposing demand flow rate (veh/h);

t_{fh} = follow-up headway (4.5 if the subject left turn is served in a shared lane; 2.5 if the subject left turn is served in an exclusive lane) (s), and

t_{cg} = critical headway = 4.5 (s).

Step 3: Compute Modified Through-Vehicle Equivalent

$$E_{L1,m} = \left(E_{L1} - 1\right) P_{lc} + 1$$

Equation 30-29

$$E_{R,m} = \left(E_{R,ap} - 1\right) P_{lc} + 1$$

Equation 30-30

where

$E_{L1,m}$ = modified through-car equivalent for a permitted left-turning vehicle,

$E_{R,m}$ = modified through-car equivalent for a protected right-turning vehicle, and

$E_{R,ap}$ = equivalent number of through cars for a protected right-turning vehicle at an access point = 2.20.

Other variables are as previously defined.

Step 4: Compute Proportion of Left Turns in Inside Through Lane

$$P_L = \frac{-b + \sqrt{b^2 - 4\, I_t\, R\, c}}{2\, I_t\, R} \quad \leq 1.0$$

Equation 30-31

with

$$b = R - P_{lt}\left[I_t + (N_{sl} + N_t + N_{sr} - 1)\,(\,[1 + I_t]E_{L1,m} - 1)\right]$$

Equation 30-32

$$c = P_{lt}\;(N_{sl} + N_t + N_{sr})$$

Equation 30-33

$$R = 1 + P_{rt}\;(E_{R,m} - 1)$$

Equation 30-34

where

R, b, c = intermediate calculation variables, and

I_t = indicator variable = 1.0 when equations are used to evaluate delay due to left turns and 0.00001 when equations are used to evaluate delay due to right turns.

Other variables are as previously defined.

If the number of through lanes on the subject intersection approach (= $N_{sl} + N_t + N_{sr}$) is equal to 1.0, then $P_L = P_{lt}$. If the right-turn vehicles are provided an exclusive right-turn lane, then P_{rt} should equal 0.0 in Equation 30-34 and in all subsequent equations.

The indicator variable I_t is used to adapt the equations to the analysis of lane volume for both left-turn- and right-turn-related delays. The variable has a value of 1.0 when applied to the evaluation of left-turn-related delays. In this situation, it models the condition in which there is one or more left-turn vehicles blocking the inside lane. In contrast, the variable has a negligibly small value when applied to right-turn-related delays. It models flow conditions in which all lanes are unblocked.

Step 5: Compute Proportion of Right Turns in Outside Through Lane

Equation 30-35

$$P_R = P_{rt} \frac{s_1/1{,}800 + N_{sl} + N_t + N_{sr} - 1}{1 - P_{rt}\left(s_1/1{,}800 + N_{sl} + N_t + N_{sr} - 2\right)\left(E_{R,m} - 1\right)} \leq 1.0$$

with

Equation 30-36

$$s_1 = \frac{1{,}800\,(1 + P_L\ I_t)}{1 + P_L\ (E_{L1,m} - 1) + (P_L\ E_{L1,m}\ I_t)}$$

where s_1 is the saturation flow rate for the inside lane (veh/h/ln). If the number of through lanes on the subject intersection approach ($= N_{sl} + N_t + N_{sr}$) is equal to 1.0, then $P_R = P_{rt}$.

Step 6: Compute Inside Lane and Outside Lane Flow Rates

Equation 30-37

$$v_1 = \frac{v_{lt}}{P_L}$$

Equation 30-38

$$v_n = \begin{cases} \dfrac{v_{rt}}{P_R} & \text{if } P_R > 0.0 \\[2ex] \dfrac{v_{lt} + v_{th} + v_{rt} - v_1}{N_{sl} + N_t + N_{sr} - 1} & \text{if } P_R = 0.0 \end{cases}$$

where

v_1 = flow rate for the inside lane (veh/h/ln), and

v_n = flow rate for the outside lane (veh/h/ln).

Other variables are as previously defined.

Step 7: Compute Intermediate Lane Flow Rate

If there are more than two lanes on the subject intersection approach, then Equation 30-39 can be used to estimate the flow rate in the intermediate lanes.

Equation 30-39

$$v_i = \frac{v_{lt} + v_{th} + v_{rt} - v_1 - v_n}{N_{sl} + N_t + N_{sr} - 2}$$

where v_i is the flow rate for lane i (veh/h/ln), and other variables are as previously defined. The flow rates in lanes 2, 3, . . . , $n - 1$ are identical and equal to the value obtained from Equation 30-39.

Step 8: Compute Merge Capacity

Equation 30-40 is used to compute the merge capacity available to through drivers waiting in the inside lane of a multilane approach.

Equation 30-40

$$c_{mg} = \frac{v_2\ e^{-v_2\ t_{lc}/3{,}600}}{1 - e^{-v_2\ t_{lc}/3{,}600}}$$

where

c_{mg} = merge capacity (veh/h),

v_2 = flow rate in the adjacent through lane (veh/h/ln), and

t_{lc} = critical merge headway = 3.7 (s).

Step 9: Compute Delay to Through Vehicles That Merge

$$d_{mg} = 3{,}600\left(\frac{1}{c_{mg}} - \frac{1}{1{,}800}\right) + 900\,T\left[\frac{v_{mg}}{c_{mg}} - 1 + \sqrt{\left(\frac{v_{mg}}{c_{mg}} - 1\right)^2 + \frac{8\,v_{mg}}{c_{mg}^2 T}}\right]$$

Equation 30-41

with

$$v_{mg} = v_1 - v_{lt} \quad \geq 0.0$$

Equation 30-42

where

d_{mg} = merge delay (s/veh),

v_{mg} = merge flow rate (veh/h/ln), and

T = analysis period duration (h).

Other variables are as previously defined.

This delay is incurred by through vehicles that stop in the inside lane and eventually merge into the adjacent through lane. The "1/1,800" term included in Equation 30-41 extracts the service time for the through vehicle from the delay estimate, such that the delay estimate represents the increase in travel time resulting from the left-turn queue.

Step 10: Compute Inside Lane Capacity

Equation 30-43 is used to compute the capacity of the inside lane for vehicles that do not merge.

$$c_{nm} = \frac{1{,}800\,(1 + P_L)}{1 + P_L\,(E_{L1} - 1) + (P_L\ E_{L1})}$$

Equation 30-43

where c_{nm} is the nonmerge capacity for the inside lane (veh/h). The unadjusted through vehicle equivalent for a left-turn vehicle E_{L1} is used in this equation to estimate the nonmerge capacity. Other variables are as previously defined.

Step 11: Compute Delay to Through Vehicles That Do Not Merge

$$d_{nm} = 3{,}600\left(\frac{1}{c_{nm}} - \frac{1}{1{,}800}\right) + 900\,T\left[\frac{v_1}{c_{nm}} - 1 + \sqrt{\left(\frac{v_1}{c_{nm}} - 1\right)^2 + \frac{8\,v_1}{c_{nm}^2 T}}\right]$$

Equation 30-44

where d_{nm} is the nonmerge delay for the inside lane (s/veh), and other variables are as defined previously. This delay is incurred by through vehicles that stop in the inside lane and wait for the queue to clear. These vehicles do not merge into the adjacent lane.

Step 12: Compute Delay to Through Vehicles in the Inside Lane

This delay is estimated as the smaller of the delay relating to the merge and nonmerge maneuvers. It is computed by using Equation 30-45.

Equation 30-45

$$d_{t,1} = \min(d_{nm}, d_{mg})$$

Step 13: Compute the Probability of Left-Turn Bay Overflow

Equation 30-46

$$p_{ov} = \left(\frac{v_{lt}}{c_l}\right)^{N_{qx,lt}+1}$$

with

Equation 30-47

$$N_{qx,lt} = \frac{N_{lt}\ L_{a,lt}}{L_h}$$

where

p_{ov} = probability of left-turn bay overflow (decimal),

$N_{qx,lt}$ = maximum queue storage for the left-turn movement (veh),

N_{lt} = number of lanes in the left-turn bay (ln),

$L_{a,lt}$ = available queue storage distance for the left-turn movement (ft/ln), and

L_h = average vehicle spacing in the stationary queue (see Equation 30-10) (ft/veh).

Other variables are as previously defined.

For an undivided cross section, the number of left-turn vehicles that can store $N_{qx,lt}$ is equal to 0.0.

Step 14: Compute Through Vehicle Delay due to Left Turns

The through vehicle delay due to left turns $d_{ap,l}$ is computed by using Equation 30-24.

DELAY DUE TO RIGHT TURNS

A vehicle turning right from the major street into an access point often delays the through vehicles that follow it. Through vehicles are delayed because they have to reduce speed to avoid a collision with the vehicle ahead, the first of which has reduced speed to avoid a collision with the right-turning vehicle. This delay can be several seconds in duration for the first few through vehicles but will always decrease to negligible values for subsequent vehicles as the need to reduce speed diminishes. For purposes of running time calculation, this delay must be averaged over all through vehicles traveling in the subject direction. The resulting average delay is computed by using Equation 30-48.

Equation 30-48

$$d_{ap,r} = 0.67\ d_{t|r}\ \frac{P_{rt}}{1 - P_{lt} - P_{rt}}$$

where

$d_{ap,r}$ = through vehicle delay due to right turns (s/veh), and

$d_{t|r}$ = through vehicle delay per right-turn maneuver (s/veh).

Other variables are as previously defined.

The variable $d_{t|r}$ in Equation 30-48 converges to 0.0 as the proportion of turning vehicles approaches 1.0. The constant 0.67 represents a calibration factor based on field data. The steps undertaken to quantify this factor are described in the remainder of this subsection. Equation 30-48 can also be used to estimate the delay due to left-turn vehicles on a one-way street. In this case, variables associated with the right-turn movement would be redefined as applicable to the left-turn movement and vice versa.

As indicated by Equation 30-48, the delay due to right turns is based on the value of several variables. The following sequence of computations can be used to estimate these values (*6*).

Step 1: Compute Minimum Speed for the First Through Vehicle

$$u_m = 1.47\ S_f - r_d\left(H_1 - h_{|\Delta<h<H_1}\right) \quad \geq u_{rt}$$

Equation 30-49

with

$$h_{|\Delta<h<H_1} = \frac{1}{\lambda} + \frac{\Delta - H_1\ e^{-\lambda(H_1-\Delta)}}{1-e^{-\lambda(H_1-\Delta)}}$$

Equation 30-50

$$H_1 = \frac{1.47S_f - u_{rt}}{r_d} + t_{cl} + \frac{L_h}{1.47S_f} \quad \geq \Delta$$

Equation 30-51

$$\lambda = \frac{1}{1/q_n - \Delta}$$

Equation 30-52

where

u_m = minimum speed of the first through vehicle given that it is delayed (ft/s),

u_{rt} = right-turn speed = 20 (ft/s),

S_f = free-flow speed (mi/h),

$h_{|\Delta<h<H_1}$ = average headway of those headways between Δ and H_1 (s/veh),

Δ = headway of bunched vehicle stream = 1.5 (s/veh),

H_1 = maximum headway that the first through vehicle can have and still incur delay (s/veh),

r_d = deceleration rate = 6.7 (ft/s^2),

t_{cl} = clearance time of the right-turn vehicle = 0.6 (s),

L_h = average vehicle spacing in stationary queue (see Equation 30-10) (ft/veh),

λ = flow rate parameter (veh/s),

q_n = outside lane flow rate = v_n/3,600 (veh/s), and

v_n = flow rate for the outside lane (veh/h/ln).

The right-turn speed u_{rt} used in Equation 30-49 and Equation 30-51 is likely to be sensitive to access point design, including the approach profile, throat width, and curb radius. For level profiles and nominal throat widths, the speed can vary from 15 to 25 ft/s for radii varying from 20 to 60 ft, respectively. A default turn speed of 20 ft/s is recommended when information is not available to make a more accurate estimate.

The flow rate for the outside lane v_n is computed by using Steps 3, 4, 5, and 6 from the Delay due to Left Turns procedure described in the previous subsection. However, the probability of a lane change P_{lc} is set equal to 1.0 when the calculations in Step 3 are made. In Steps 4 and 5, the variable I_t is set equal to 0.00001. The proportion of right-turning vehicles in the shared lane P_R is also computed at this point and used in a later step.

Step 2: Compute Delay to the First Through Vehicle

Equation 30-53

$$d_1 = \frac{(1.47 S_f - u_m)^2}{2\,(1.47 S_f)} \left(\frac{1}{r_d} + \frac{1}{r_a} \right)$$

where d_1 = conditional delay to first through vehicle (s/veh), r_a = acceleration rate = 3.5 (ft/s²), and other variables are as previously defined.

Step 3: Compute Delay to the Second Through Vehicle

Equation 30-54

$$d_2 = d_1 - (h_{|\Delta<h<H_2} - \Delta)$$

with

Equation 30-55

$$h_{|\Delta<h<H_2} = \frac{1}{\lambda} + \frac{\Delta - H_2\ e^{-\lambda(H_2-\Delta)}}{1 - e^{-\lambda(H_2-\Delta)}}$$

Equation 30-56

$$H_2 = d_1 + \Delta$$

where d_2 is the conditional delay to Vehicle 2 (s/veh), and other variables are as previously defined.

Step 4: Compute Delay to the Third and Subsequent Through Vehicles

Equation 30-57

$$d_i = d_{i-1} - (h_{|\Delta<h<H_i} - \Delta)$$

with

Equation 30-58

$$h_{|\Delta<h<H_i} = \frac{1}{\lambda} + \frac{\Delta - H_i\ e^{-\lambda(H_i-\Delta)}}{1 - e^{-\lambda(H_i-\Delta)}}$$

Equation 30-59

$$H_i = d_{i-1} + \Delta$$

where d_i is the conditional delay to vehicle i (i = 3, 4, . . . ,) (s/veh), and other variables are as previously defined. As shown by Equation 30-54 and Equation 30-57, the delay to each subsequent through vehicle is less than or equal to that of the preceding vehicle. In fact, the sequence of delays always converges to zero when the average flow rate in the outside lane is less than $1/\Delta$.

Step 4 should be repeated for the third and subsequent through vehicles until the delay computed for vehicle i is less than 0.1 s. In general, this criterion results in delay being computed for only the first two or three vehicles.

Step 5: Compute Through Vehicle Delay per Right-Turn Maneuver

The through vehicle delay for the first two vehicles is computed by using Equation 30-60.

$$d_{t|r} = d_1\left(1 - e^{-\lambda(H_1 - \Delta)}\right)(1 - P_R) + d_2\left(1 - e^{-\lambda(H_1 - \Delta)}\right)\left(1 - e^{-\lambda(H_2 - \Delta)}\right)(1 - P_R)^2$$

Equation 30-60

where $d_{t|r}$ is the through vehicle delay per right-turn maneuver (s/veh), and other variables are as previously defined. If three or more vehicles are delayed, then an additional term needs to be added to Equation 30-60 for each subsequent vehicle. In this situation, Equation 30-61 can be used to compute the delay for any number of vehicles.

$$d_{t|r} = \sum_{i=1}^{\infty}\left[d_i \times \prod_{j=1}^{i}\left(1 - e^{-\lambda(H_j - \Delta)}\right) \times (1 - P_R)^i\right]$$

Equation 30-61

Step 6: Compute Through Vehicle Delay due to Right Turns

The through vehicle delay due to right turns $d_{ap,r}$ is computed by using Equation 30-48.

4. QUICK ESTIMATION METHOD

INTRODUCTION

This section describes a simplified method for evaluating the operation of a coordinated street segment with signalized boundary intersections. The method addresses automobile operation. It is focused on the analysis of the through movement at the boundary intersections. This method can be used when minimal data are available for the analysis and only approximate results are desired.

INPUT DATA REQUIREMENTS

The overall data requirements are summarized in Exhibit 30-6. Some of the input requirements may be met by assumed values or default values. Other data items are site-specific and must be obtained in the field. The objective of using the quick estimation method is to minimize the need for the collection of detailed field data.

Exhibit 30-6
Input Data Requirements for the Quick Estimation Method

Data Category	Location	Input Data Element
Traffic characteristics	Boundary intersection	Through-demand flow rate
		Through-saturation flow rate
		Volume-to-capacity ratio of the upstream movements
	Segment	Platoon ratio
		Midsegment flow rate
		Midsegment delay
Geometric design	Boundary intersection	Number of through lanes
		Upstream intersection width
	Segment	Number of through lanes
		Segment length
		Restrictive median length
		Nonrestrictive median length
		Proportion of segment with curb
		Number of access point approaches
Signal control	Boundary intersection	Effective green-to-cycle-length ratio
		Cycle length
Other	Segment	Analysis period duration
		Speed limit

At a minimum, the analyst must provide traffic volumes and the approach-lane configuration for the subject intersection. Default values for several variables are specifically identified in the methodology and integrated into the method. These values have been selected to be generally representative of typical conditions. Additional default values are identified in Section 3 of Chapter 17, Urban Street Segments.

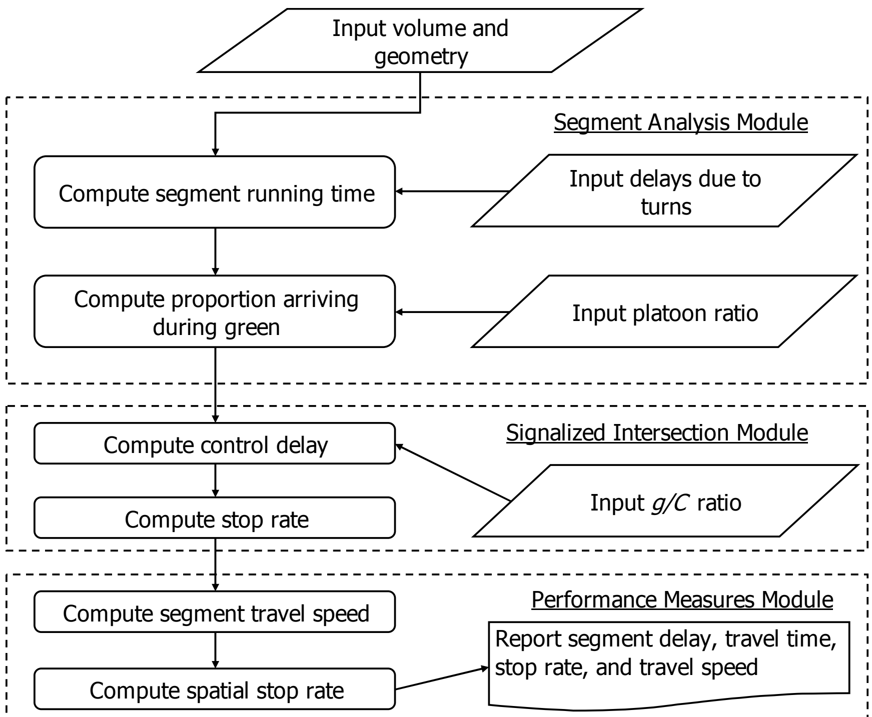
METHODOLOGY

The analysis consists of five computational steps. These steps are

- Determine running time,
- Determine proportion arriving during green,
- Determine through control delay,
- Determine through stop rate, and
- Determine travel speed and spatial stop rate.

Each step is executed in the sequence presented in the preceding list. This sequence is illustrated by the flow chart in Exhibit 30-7. The rectangles with rounded corners indicate the computational steps. The parallelograms indicate where input data are needed.

Exhibit 30-7
Quick Estimation Method for Urban Street Segments



The computations associated with each step identified in Exhibit 30-7 are described in Section 2 of Chapter 17. These computations are conveniently illustrated here in a series of worksheets; each worksheet corresponds to one or two of the calculation steps.

The first of the computational worksheets is the Running Time worksheet. It is shown as Exhibit 30-8 (values shown apply to the Example Problem, as discussed in a subsequent section).

Exhibit 30-8
Quick Estimation Running Time Worksheet

RUNNING TIME WORKSHEET

General Information		Site Information	
Analyst	JME	Street	Texas Avenue
Agency or Company	ACME Engr.	Jurisdiction	
Date Performed	9/30/10	Analysis Year	2010
Analysis Time Period	5:30 p.m. to 5:45 p.m.	Analysis Level	planning

Input Data	Segment 1		Segment 2	
Direction of travel	**EB/NB**	**WB/SB**	**EB/NB**	**WB/SB**
Segment Data				
Number of through lanes for length of segment (N_{th}), ln	2	2		
Speed limit (S_{pl}), mi/h	35	35		
Midsegment volume (v_m), veh/h	1,150	1,150		
Total delay due to turns into access points (Σd_{ap}), s/veh	0.52	0.52		
Delay due to other midsegment sources (d_{other}), s/veh	0	0		
Length of segment (L), ft	1,800	1,800		
Width of upstream boundary intersection (W_i), ft	50	50		
Length of segment with restrictive median (L_{rm}), ft	0	0		
Length of segment with nonrestrictive median (L_{nr}), ft	0	0		
Start-up lost time (l_1), s	2.0	2.0		
Access Data				
Proportion of street with curb on right-hand side (p_{curb})	0.70	0.70		
Number of access points on right-hand side (N_{ap})	4	4		
Running Time Computation				
Adjusted segment length (L_{adj}), ft $L_{adj} = L - W_i$	1,750	1,750		
Proportion of segment length with restrictive median (p_{rm}) $p_{rm} = L_{rm}/L_{adj}$	0	0		
Speed constant (S_0), mi/h $S_0 = 25.6 + 0.47\ S_{pl}$	42.1	42.1		
Adjustment for cross section (f_{CS}), mi/h $f_{CS} = 1.5\ p_{rm} - 0.47\ p_{curb} - 3.7\ p_{curb}\ p_{rm}$	-0.3	-0.3		
Access point density (D_a), access points/mi $D_a = 5280\ (N_{ap,EB/NB} + N_{ap,WB/SB})/L_{adj}$	24.1	24.1		
Adjustment for access points (f_A), mi/h $f_A = -0.078\ D_a/N_{th}$	-0.9	-0.9		
Base free-flow speed (S_{fo}), mi/h $S_{fo} = S_0 + f_{CS} + f_A$	40.8	40.8		
Segment length adjustment factor (f_L) $f_L = 1.02 - 4.7\ (S_{fo} - 19.5)/\max(L, 400) \leq 1.0$	0.96	0.96		
Free-flow speed (S_f), mi/h $S_f = S_{fo}\ f_L$	39.3	39.3		
Proximity adjustment factor (f_v) $f_v = \dfrac{2}{1 + \left(1 - \dfrac{v_m}{52.8\ N_{th}\ S_f}\right)^{0.21}}$	1.03	1.03		
Running time (t_R), s $t_R = \dfrac{6.0 - l_1}{0.0025\ L} + \dfrac{3{,}600\ L}{5{,}280\ S_f} f_v + \sum d_{ap} + d_{other}$	33.7	33.7		

Note: The first term in the running time equation is only applicable to segments with signalized or STOP- or YIELD-controlled boundary intersections.

The Running Time worksheet combines input data describing the segment geometric design, speed limit, volume, and access point frequency to estimate the base free-flow speed. This speed is then adjusted for segment length effects to obtain the expected free-flow speed. The free-flow speed is then used to estimate a free-flow travel time, which is adjusted for the proximity of other vehicles. Delay that is caused by turns into access points or other sources is added to the adjusted travel time. Default values for the delay due to turns at midsegment access points are listed in Exhibit 17-13 in Chapter 17. These defaults can be used when other, more accurate estimates of this delay are not available. The result of these adjustments is an estimate of the expected segment running time.

The second of the computational worksheets is the Proportion Arriving During Green worksheet. It is shown as Exhibit 30-9. This worksheet is designed for the analysis of the segment through-lane group. It documents the calculation of the proportion of vehicles that arrive during the green indication. Input data include the effective green-to-cycle-length ratio and platoon ratio.

Exhibit 30-9
Quick Estimation Proportion Arriving During Green Worksheet

PROPORTION ARRIVING DURING GREEN WORKSHEET				
General Information				
Project Description	Texas Avenue, 5:30 p.m. to 5:45 p.m.			
Input Data				
	Segment 1		**Segment 2**	
Direction of travel	**EB/NB**	**WB/SB**	**EB/NB**	**WB/SB**
Signal Timing Data				
Effective green-to-cycle-length ratio (g/C)	0.47	0.47		
Traffic Data				
Platoon ratio (R_p)	1.43	0.67		
Proportion Arriving During Green Computation				
Proportion arriving during green (P) $P = R_p\,(g/C)$	0.67	0.31		

The third computational worksheet is the Control Delay worksheet. It is shown as Exhibit 30-10. This worksheet is designed for the analysis of the segment through-lane group. Input variables include the analysis period duration, cycle length, effective green-to-cycle-length ratio, volume, saturation flow rate, and lanes. The proportion of arrivals during green is obtained from the previous worksheet.

The control delay is computed as the sum of two components. The first component to be computed is the uniform delay. The notation "min(1, X)" is shown in the equation used to compute this delay. It means that the value to be substituted for this text is the smaller of 1.0 and the volume-to-capacity ratio.

Exhibit 30-10
Quick Estimation Control Delay Worksheet

CONTROL DELAY WORKSHEET				
General Information				
Project Description	Texas Avenue, 5:30 p.m. to 5:45 p.m.			
Input Data				
Analysis period (T), h: 0.25	**Segment 1**		**Segment 2**	
Direction of travel	**EB/NB**	**WB/SB**	**EB/NB**	**WB/SB**
Signal Timing Data				
Cycle length (C), s	100	100		
Effective green-to-cycle-length ratio (g/C)	0.47	0.47		
Traffic Data				
Through-lane group volume (v_{th}), veh/h	968	950		
Lane group saturation flow rate (s), veh/h/ln	1,800	1,800		
Proportion of arrivals during green (P)	0.67	0.31		
Volume-to-capacity ratio (X_u) of the upstream movements	0.57	0.57		
Geometric Design Data				
Number of through lanes (N_{th}), ln	2	2		
Delay Computation				
Capacity (c), veh/h $c = N_{th}\, s\, g/C$	1,692	1,692		
Volume-to-capacity ratio (X) $X = v_{th}/c$	0.57	0.56		
Uniform delay (d_1), s/veh $d_1 = \frac{0.5\, C\, (1 - g/C)^2}{1 - [\min(1, X)\, g/C]}$	19.2	19.1		
Upstream filtering adjustment factor (I) $I = 1.0 - 0.91\, X_u^{2.68} \geq 0.090$	0.80	0.80		
Incremental delay (d_2), s/veh $d_2 = 900\, T \left[(X-1) + \sqrt{(X-1)^2 + \frac{4\, I\, X}{c\, T}} \right]$	1.13	1.08		
Progression adjustment factor (PF) $PF = (1 - P)/(1 - g/C)$	0.62	1.30		
Control delay (d), s/veh $d = d_1\,(PF) + d_2$	13.0	25.8		

The second delay component is the incremental delay, which is based on the upstream filtering adjustment factor. This factor requires the variable X_u. This variable can be estimated as the volume-to-capacity ratio of the segment through-lane group at the upstream signalized intersection. Additional detail on the calculation of this ratio for long segments is provided in Section 1 of Chapter 18, Signalized Intersections.

The fourth computational worksheet is the Stop Rate worksheet. It is shown as Exhibit 30-11. This worksheet is designed for the analysis of the segment through-lane group. The input variables are the same as those needed for the Control Delay worksheet with the addition of speed limit. The average speed during the analysis period is estimated by using the equation provided. If the average speed is known, it should be substituted for the estimated value.

Exhibit 30-11
Quick Estimation Stop Rate Worksheet

STOP RATE WORKSHEET				
General Information				
Project Description: Texas Avenue, 5:30 p.m. to 5:45 p.m.				
Input Data				
Analysis period (T), h: 0.25	**Segment 1**		**Segment 2**	
Direction of travel	**EB/NB**	**WB/SB**	**EB/NB**	**WB/SB**
Signal Timing Data				
Cycle length (C), s	100	100		
Effective green-to-cycle-length ratio (g/C)	0.47	0.47		
Traffic Data				
Through-lane group volume (v_{th}), veh/h	968	950		
Lane group saturation flow rate (s), veh/h/ln	1,800	1,800		
Proportion of arrivals during green (P)	0.67	0.31		
Speed limit (S_{pl}), mi/h	35	35		
Incremental delay (d_2), s/veh	1.13	1.08		
Geometric Design Data				
Number of through lanes (N_{th}), ln	2	2		
Stop Rate Computation				
Effective green time (g), s $g = C(g/C)$	47	47		
Effective red time (r), s $r = C - g$	53	53		
Capacity (c), veh/h $c = N_{th}\, s\, g/C$	1,692	1,692		
Volume-to-capacity ratio (X) $X = v_{th}/c$	0.57	0.56		
Average speed (S_a), mi/h $S_a = 0.90\,(25.6 + 0.47\, S_{pl})$	39.9	39.9		
Threshold acceleration–deceleration delay, s $(1 - P)\, gX$	8.8	18.1		
Acceleration–deceleration delay (d_a), s $d_a = 0.393\,(S_a - 5.0)^2/S_a$	12.0	12.0		
Deterministic stop rate (h_1), stops/veh $h_1 = \frac{1 - P(1 + d_a/g)}{1 - PX}$: *if* $d_a \le (1-P)gX$; $h_1 = \frac{(1-P)(r - d_a)}{r - (1-P)gX}$: *if* $d_a > (1-P)gX$	0.30	0.74		
Second-term back-of-queue size (Q_2), veh/ln $Q_2 = c\, d_2/(3{,}600\, N_{th})$	0.26	0.25		
Full stop rate (h), stops/veh $h = h_1 + 3{,}600\, N_{th}\, Q_2/(v_{th}\, C)$	0.32	0.76		

The stop rate is computed as the sum of two components. The first component to be computed is the deterministic stop rate. Two equations are available for this computation. The correct equation to use is based on a check of the acceleration–deceleration delay relative to the computed threshold value.

The second stop rate component is based on the second-term back-of-queue size. This queue represents the average number of vehicles that are unserved at the end of the green interval. It is based on the incremental delay computed for the Control Delay worksheet.

The fifth computational worksheet is the Travel Speed and Spatial Stop Rate worksheet. It is shown as Exhibit 30-12. This worksheet is designed for the analysis of the segment through-lane group. The input values include segment length and the full stop rate associated with other midsegment events (e.g., turns at access points). The other input data listed represent computed values and are obtained from the previous worksheets.

Exhibit 30-12
Quick Estimation Travel Speed and Spatial Stop Rate Worksheet

TRAVEL SPEED AND SPATIAL STOP RATE WORKSHEET				
General Information				
Project Description	Texas Avenue, 5:30 p.m. to 5:45 p.m.			
Input Data				
	Segment 1		**Segment 2**	
Direction of travel	**EB/NB**	**WB/SB**	**EB/NB**	**WB/SB**
Length of segment (L), ft	1,800	1,800		
Base free-flow speed (S_{fo}), mi/h	40.8	40.8		
Running time (t_R), s	33.7	33.7		
Control delay (d), s/veh	13.0	25.8		
Full stop rate (h), stops/veh	0.32	0.76		
Full stop rate due to other midsegment sources (h_{other}), stops/veh	0	0		
Travel Speed Computation				
Travel time (T_T), s $T_T = t_R + d$	46.7	59.5		
Travel speed ($S_{T,seg}$), mi/h $S_{T,seg} = \frac{3{,}600\,L}{5{,}280\,T_T}$	26.3	20.6		
Spatial Stop Rate Computation				
Total stop rate (h_T), stops/veh $h_T = h + h_{other}$	0.32	0.76		
Spatial stop rate (H_{seg}), stops/mi $H_{seg} = \frac{5{,}280\,h_T}{L}$	0.94	2.22		
Level of Service Computation				
Travel speed as a percentage of base free-flow speed (R) $R = 100\ S_{T,seg} / S_{fo}$	64.5	50.6		
Level of service (Exhibit 17-1)	C	C		

EXAMPLE PROBLEM

The Urban Street Segment

The total length of an undivided urban street segment is 1,800 ft. It is shown in Exhibit 30-13. Both of the boundary intersections are signalized. The street has a four-lane cross section with two lanes in each direction. There are left-turn bays on the subject segment at each signalized intersection.

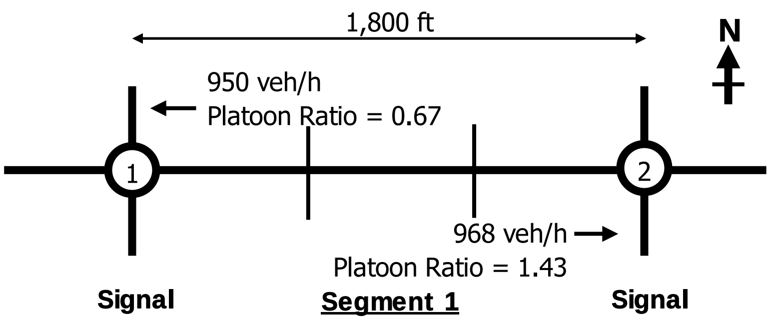


Exhibit 30-13
Quick Estimation Example Problem

The segment has two access point intersections. Each intersection has two STOP-controlled side-street approaches. The segment has some additional driveways on each side of the street; however, their turn movement volumes are too low during the analysis period for them to be considered "active."

The Question

What are the travel speed, spatial stop rate, and level of service (LOS) during the analysis hour for through automobile traffic in both directions of travel along the segment?

The Facts

Some details of the segment are shown in Exhibit 30-13. Both boundary intersections are signalized. The following additional information is known about the street segment:

Through saturation flow rate: 1,800 veh/h/ln

Midsegment volume: 1,150 veh/h

Midsegment delay: 0.52 s/veh

Number of through lanes at boundary intersection: 2

Upstream intersection width: 50 ft

Number of through lanes on segment: 2

Proportion of street with curb: 0.70

g/*C* ratio: 0.47

Cycle length: 100 s

Analysis period: 0.25 h

Speed limit: 35 mi/h

Percent left turns at access points: 6%

Percent right turns at access points: 8%

Selected Calculations

1. Compute total delay due to turns into access points	Midsegment lanes = 2 lanes Midsegment lane volume = 575 veh/h/ln Interpolate in Exhibit 17-13 to obtain 0.37 s/veh/pt through vehicle delay. Number of active access points = 2 Percent turns = 7% [= (6 + 8)/2] Total delay per access pt. = 7/10 × 0.37 = 0.26 s/veh/pt Total delay per segment = 2 × 0.26 = 0.52 s/veh
2. Compute upstream filtering factor	No information was available about the volume-to-capacity ratio for the upstream movements, so this ratio was estimated to equal the volume-to-capacity ratio for the subject movement.

Results

The calculations are shown in Exhibit 30-8 to Exhibit 30-12. The travel speed for the eastbound direction is 26.3 mi/h. The travel speed for the westbound direction is 20.6 mi/h. The eastbound and westbound spatial stop rates are 0.94 and 2.22 stops/mi, respectively. The travel speed for the eastbound direction is 64.5 percent (= 26.3/40.8 × 100) of the base free-flow speed and, according to Exhibit 17-2, corresponds to LOS C. The westbound LOS is similarly computed to be C.

5. FIELD MEASUREMENT TECHNIQUES

This section describes two techniques for estimating key vehicular traffic characteristics by using field data. The first technique is used to estimate free-flow speed. The second technique is used to estimate average travel speed.

FREE-FLOW SPEED

The following steps can be used to determine the free-flow speed for vehicular traffic on an urban street segment.

Step 1. Conduct a spot-speed study at a midsegment location during low-volume conditions. Record the speed of 100 or more free-flowing passenger cars. A car is free-flowing when it has a headway of 8 s or more to the vehicle ahead and 5 s or more to the vehicle behind in the same traffic lane.

Step 2. Compute the average of the spot speeds S_{spot} and their standard deviation σ_{spot}.

Step 3. Compute the segment free-flow speed S_f as a space mean speed by using Equation 30-62.

$$S_f = S_{spot} - \frac{\sigma_{spot}^2}{S_{spot}}$$

Equation 30-62

where

S_f = free-flow speed (mi/h),

S_{spot} = average spot speed (mi/h), and

σ_{spot} = standard deviation of spot speeds (mi/h).

Step 4. If the base free-flow speed S_{fo} is also desired, it can be computed by using Equation 30-63.

$$S_{fo} = \frac{S_f}{f_L}$$

Equation 30-63

with

$$f_L = 1.02 - 4.7\,\frac{S_f - 19.5}{\max(L_s\,,\,400)} \quad \le 1.0$$

Equation 30-64

where

S_{fo} = base free-flow speed (mi/h),

S_f = free-flow speed (mi/h),

L_s = distance between adjacent signalized intersections (ft), and

f_L = signal spacing adjustment factor.

Equation 30-64 was originally derived to use the base free-flow speed S_{fo} in the numerator of its second term. However, it is sufficient for this application to substitute the free-flow speed S_f.

Equation 30-64 was derived by using signalized boundary intersections. For more general applications, the definition of distance L_s is broadened such that it equals the distance between the two intersections that (*a*) bracket the subject segment and (*b*) each have a type of control that can impose on the subject through movement a legal requirement to stop or yield.

AVERAGE TRAVEL SPEED

The following steps can be used to determine the average travel speed for vehicular traffic on an urban street segment.

Step 1. Identify the time of the day (e.g., morning peak, evening peak, off-peak) during which the study will be conducted. Identify the segments to be evaluated.

Step 2. Conduct the test-car travel time study for the identified segments during the identified study period. The following factors should be considered before, or during, the field study.

- The number of travel time runs to be conducted will depend on the range of speeds found on the street. Six to 12 runs for each traffic-volume condition are typically adequate. The analyst should determine the minimum number of runs on the basis of guidance provided elsewhere (*7*).
- The objective of the data collection is to obtain the information identified in the Travel Time Field Worksheet (i.e., vehicle location and arrival and departure times at each boundary intersection). This worksheet is shown in Exhibit 30-14. In general, each row of this worksheet represents the data for one direction of travel on one segment. If the street serves traffic in two travel directions, separate worksheets are typically used to record the data for each direction of travel.
- The equipment used to record the data may include a global positioning system–equipped laptop computer or simply a pair of stopwatches. If available, an instrumented test car should be used to reduce labor requirements and to facilitate recording and analysis.
- During the test run, the average-car technique is typically used and requires that the test car travel at the average speed of the traffic stream, as judged by its driver (*7*).
- The cumulative travel time is recorded as the vehicle passes the center of each boundary intersection. Whenever the test car stops or slows (i.e., 5 mi/h or less), the observer uses a second stopwatch to measure the duration of time the vehicle is stopped or slowed. This duration (and the cause of the delay) is recorded on the worksheet on the same row that is associated with the next boundary intersection to be reached. The rows are intentionally tall so that a midsegment delay and the signal delay can both be recorded in the same cell.
- Test-car runs should begin at different time points in the signal cycle to avoid having all runs start from a “first in platoon” position.

- Some midsegment speedometer readings should also be recorded to check on unimpeded travel speeds and to see how they relate to the estimated free-flow speed.

Exhibit 30-14
Travel Time Field Worksheet

TRAVEL TIME FIELD WORKSHEET						
General Information			**Site Information**			
Analyst			Street			
Agency or Company			Jurisdiction			
Date Performed			Analysis Year			
Analysis Time Period			Direction of Travel			
Field Data						
Location (typically a boundary intersection)	**Run Number: ______**			**Run Number: ______**		
	Cumulative Travel Time at Location (s)	**Delays due to Slow or Stop**		**Cumulative Travel Time at Location (s)**	**Delays due to Slow or Stop**	
		Cause [a]	**Delay Time (s)**		**Cause [a]**	**Delay Time (s)**

Note: [a] Cause of delay: Ts - signal; Lt - left turn; Pd - pedestrian; Pk - parking; Ss - STOP sign; Ys - YIELD sign.

Step 3. The cumulative travel time observations between adjacent boundary intersections are subtracted to obtain the travel time for the corresponding segment. This travel time can be averaged for all test runs to obtain an average segment travel time. This average is then divided into the segment length to obtain an estimate of the average travel speed. This speed should be computed for each direction of travel for the segment.

The data should be summarized to provide the following statistics for each segment travel direction: average travel speed, average delay time for the boundary intersection, and average delay time for other sources (pedestrian, parking maneuver, etc.).

The average segment travel time for each of several consecutive segments in a common direction of travel can be added to obtain the total travel time for the facility. This total travel time can then be divided into the facility length (i.e., the total length of all segments) to obtain the average travel speed for the facility. This calculation should be repeated to obtain the average travel speed for the other direction of travel.

6. COMPUTATIONAL ENGINE DOCUMENTATION

This section uses a series of flowcharts and linkage lists to document the logic flow for the computational engine.

FLOWCHARTS

The methodology flowchart is shown in Exhibit 30-15. The methodology is shown to consist of five main modules:

- Setup Module,
- Segment Evaluation Module,
- Segment Analysis Module,
- Delay due to Turns Module, and
- Performance Measures Module.

This subsection provides a separate flowchart for each of these modules.

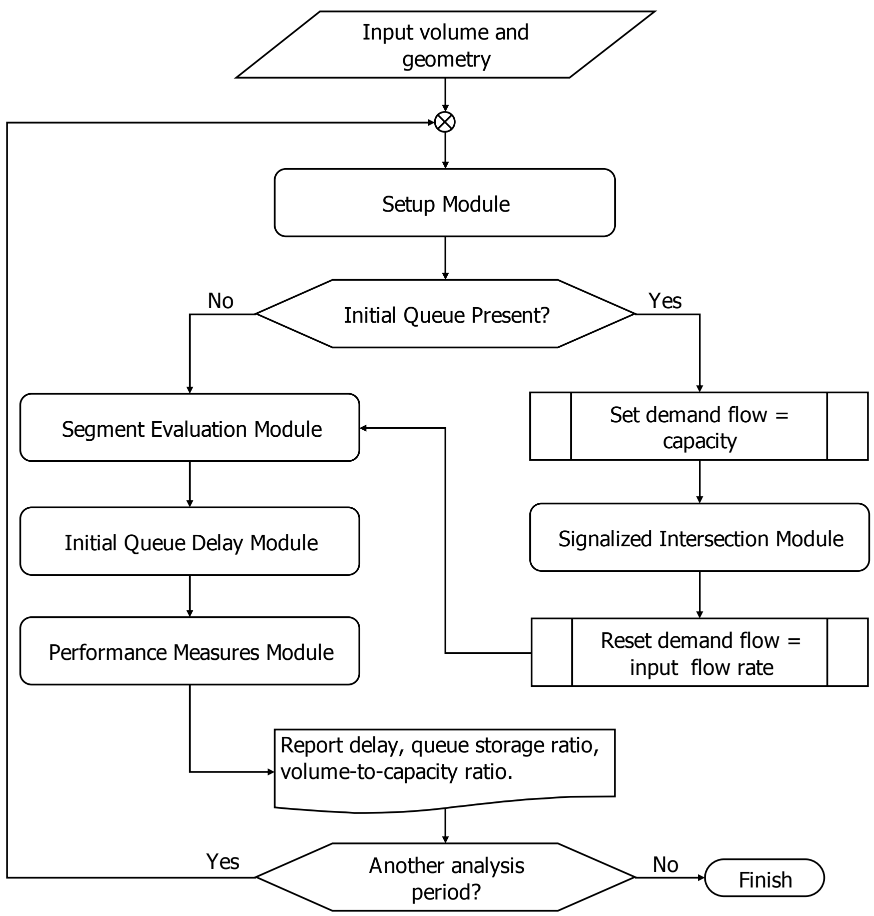
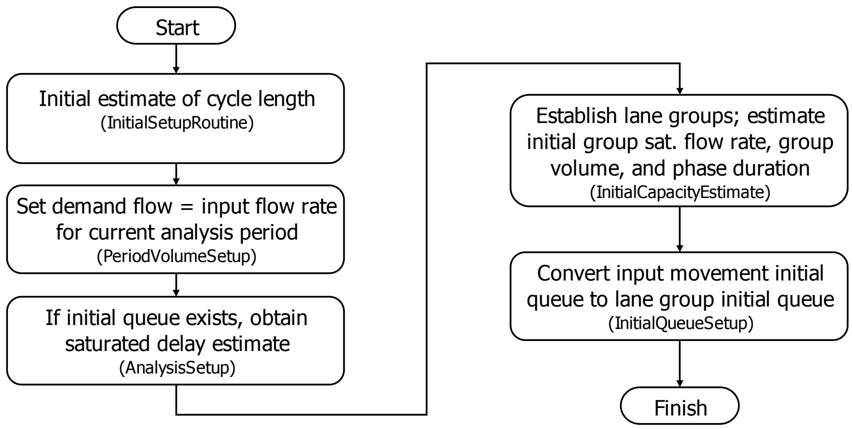


Exhibit 30-15
Methodology Flowchart

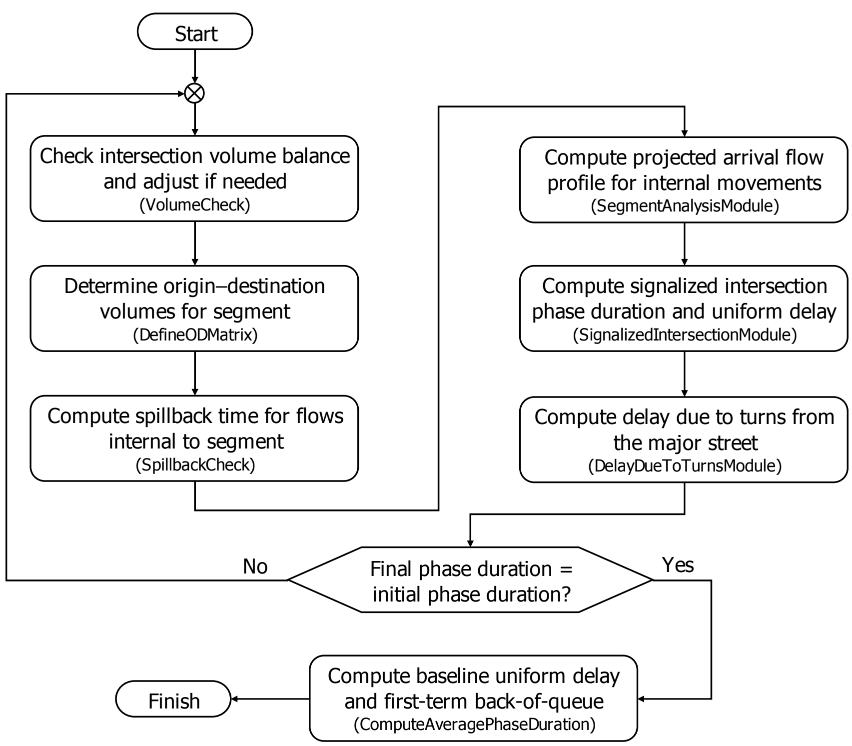
The Setup Module is shown in Exhibit 30-16. This module consists of four main routines, as shown in the large rectangles of the exhibit. The main function of each routine, as well as the name given to it in the computational engine, is also shown in the exhibit. These routines and the Initial Queue Delay Module are described in Section 7 of Chapter 31, Signalized Intersections: Supplemental.

Exhibit 30-16
Setup Module



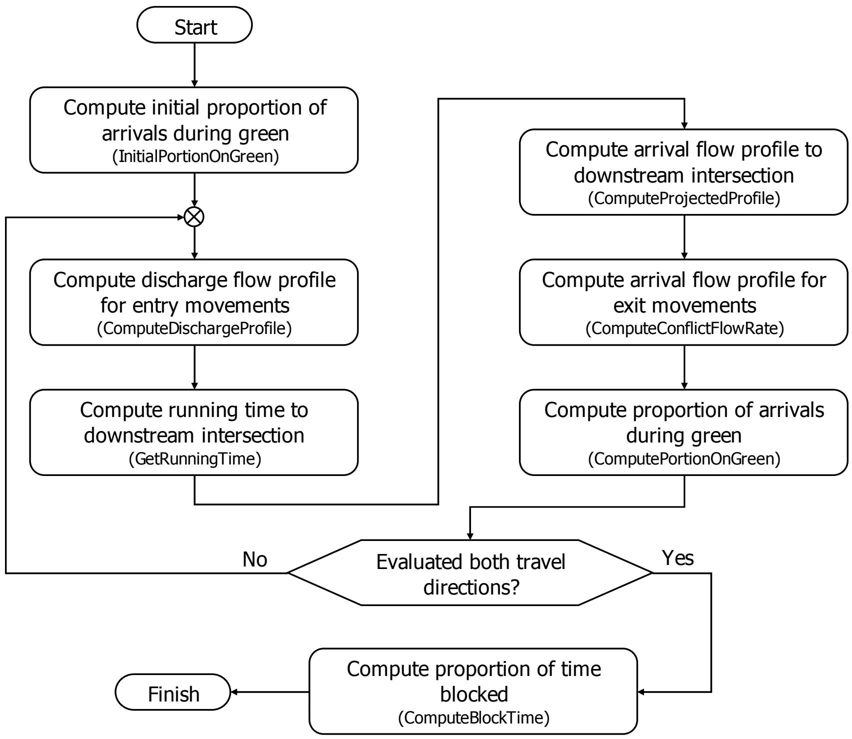
The Segment Evaluation Module is shown in Exhibit 30-17. This module consists of seven main routines. The main function of each routine, as well as the name given to it in the computational engine, is also shown in the exhibit. The Segment Analysis Module and the Delay due to Turns Module are outlined in the next two exhibits. The Signalized Intersection Module and the Compute Average Phase Duration routine are described in Section 7 of Chapter 31. The Volume Check, Define Origin–Destination Matrix, and Spillback Check routines are described further in the next subsection.

Exhibit 30-17
Segment Evaluation Module



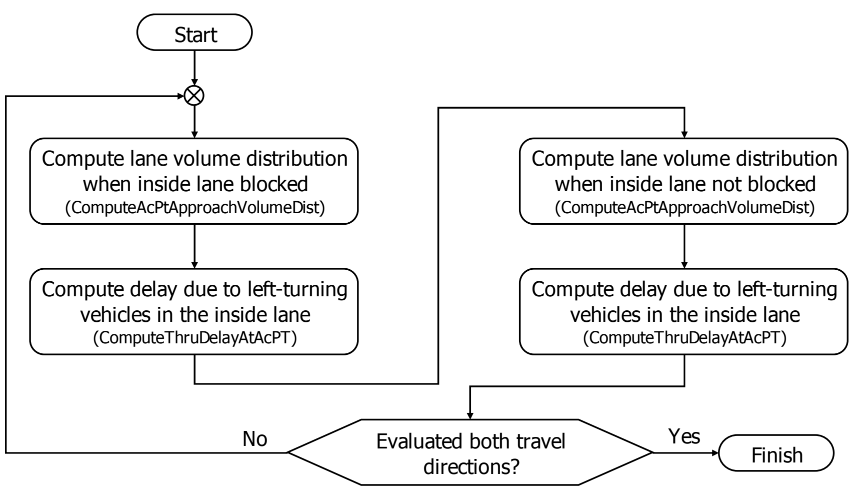
The Segment Analysis Module is shown in Exhibit 30-18. This module consists of seven main routines, six of which are implemented for both segment travel directions. The main function of each routine, as well as the name given to it in the computational engine, is also shown in the exhibit. These routines are described further in the next subsection.

Exhibit 30-18
Segment Analysis Module



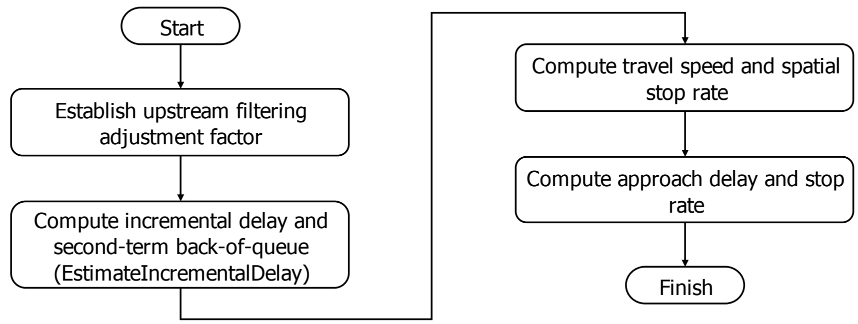
The Delay due to Turns Module is shown in Exhibit 30-19. This module consists of two main routines, each of which is implemented for both segment travel directions. The main function of each routine, as well as the name given to it in the computational engine, is also shown in the exhibit. These routines are described further in the next subsection.

Exhibit 30-19
Delay due to Turns Module



The Performance Measures Module is shown in Exhibit 30-20. This module consists of four routines. The main function of each routine is also shown in the exhibit. One of the routines (i.e., Estimate Incremental Delay) is complicated enough to justify its development as a separate entity in the computational engine. This routine is described in Section 7 of Chapter 31, Signalized Intersections: Supplemental.

Exhibit 30-20
Performance Measures Module



LINKAGE LISTS

This subsection uses linkage lists to describe the main routines that make up the computational engine. Each list is provided in a table that identifies the routine and the various subroutines that it references. Conditions for which the subroutine is used are also provided.

The lists are organized by module, as described in the previous subsection. A total of three tables are provided to address the following three modules:

- Segment Evaluation Module,
- Segment Analysis Module, and
- Delay due to Turns Module.

The linkage list for the Segment Evaluation Module is provided in Exhibit 30-21. The main routines are listed in Column 1 and were previously identified in Exhibit 30-17.

The linkage list for the Segment Analysis Module is provided in Exhibit 30-22. The main routines are listed in Column 1 and were previously identified in Exhibit 30-18.

Finally, the linkage list for the Delay due to Turns Module is provided in Exhibit 30-23. The main routines are listed in Column 1 and were previously identified in Exhibit 30-19.

Exhibit 30-21
Segment Evaluation Module Routines

Routine	Subroutine	Conditions for Use
VolumeCheck	Ensure that discharge volume for each entry movement does not exceed its capacity.	Apply for both segment travel directions.
DefineODMatrix	ComputeODs (compute origin–destination volume for movements that enter and exit segment).	Apply to all intersections on segment and for both segment travel directions.
SpillbackCheck	ComputeSpillbackTime (compute spillback time for each exit movement at the downstream boundary intersection).	Apply for both segment travel directions.
SegmentAnalysisModule	See Exhibit 30-22.	
SignalizedIntersectionModule	See Section 7 of Chapter 31.	--
DelayDueToTurnsModule	See Exhibit 30-23.	
ComputeAveragePhaseDuration	See Section 7 of Chapter 31.	--

Exhibit 30-22
Segment Analysis Module Routines

Routine	Subroutine	Conditions for Use
InitialPortionOnGreen	Compute proportion of arrivals during green (P) based on current signal timing.	None
ComputeDischargeProfile	Compute discharge flow rate for each 1-s interval of signal cycle at upstream boundary intersection.	Apply to each upstream boundary intersection movement that enters segment.
GetRunningTime	Compute running time on length of street between upstream boundary intersection and subject downstream intersection.	Apply to all intersections on the segment and for both segment travel directions.
ComputeProjectedProfile	Compute arrival flow profile reflecting dispersion of platoons formed at upstream boundary intersection.	Apply to each upstream boundary intersection movement that enters segment.
ComputeConflictRate	Use arrival flow profile and origin–destination matrix to compute arrival flow rate for movements at subject intersection.	Apply to all intersections on the segment and for both segment travel directions.
	Compute conflicting flow rate at access point intersections on basis of the projected arrivals at each intersection.	Apply to all access point intersections and for both segment travel directions.
ComputePortionOnGreen	For each exit movement, compute count of vehicles arriving at downstream boundary intersection during green.	Apply to each downstream boundary intersection.
ComputeBlockTime	Use computed conflicting flow rates at each access point intersection to compute the proportion of time blocked for each nonpriority movement.	Apply to all access point intersections and for both travel segment travel directions.

Exhibit 30-23
Delay due to Turns Module Routines

Routine	Subroutine	Conditions for Use
ComputeAcPtApproach-VolumeDist	Compute the volume for each lane on the approach to the access point intersection when blocked by a left-turning vehicle.	Apply lane volume routine for case in which inside lane is blocked by a turning vehicle. Apply to all access point intersections and for both segment travel directions.
	Compute the volume for each lane on the approach to the access point intersection when *not* blocked by a left-turning vehicle.	Apply lane volume routine for case in which inside lane is *not* blocked by a turning vehicle. Apply to all access point intersections and for both segment travel directions.
ComputeThruDelayAtAcPT	Compute the probability of left-turn bay overflow at access point intersection.	If segment is undivided then probability of bay overflow is 1.0.
	Compute the delay to through movements due to a left turn at an access point. Based on lane volume estimate for case in which inside lane is blocked by a turning vehicle.	Apply to all access point intersections and for both segment travel directions.
	Compute the delay to through movements due to a right turn at an access point. Based on lane volume estimate for case in which inside lane is *not* blocked by a turning vehicle.	Apply to all access point intersections and for both segment travel directions.

7. REFERENCES

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