CHAPTER 15

URBAN STREETS

CONTENTS

EXHIBITS

I. INTRODUCTION

SCOPE OF THE METHODOLOGY

Background and underlying concepts for this chapter are in Chapter 10

This chapter provides a methodology for analyzing urban streets. This methodology also may be used to analyze suburban streets that have a traffic signal spacing of 3.0 km or less. Both one-way and two-way streets can be analyzed with this methodology; however, each travel direction of the two-way street requires a separate analysis.

The methodology described in this chapter can be used to assess mobility on an urban street. The degree of mobility provided is assessed in terms of travel speed for the through-traffic stream. A street's access is not assessed with this methodology. However, the level of access provided by a street also should be considered when evaluating its performance, especially if the street is intended to provide access. Factors that favor mobility often reflect minimal levels of access and vice versa.

The methodology described in this chapter focuses on mobility; urban streets with mobility tend to be at least 3 km long (or in downtown areas, 1.5 km). A shorter street also may be analyzed; however, it is likelier that its primary function is access. Access can be evaluated to some degree through an analysis of the individual intersections along the street.

LIMITATIONS OF THE METHODOLOGY

The urban streets methodology does not directly account for the following conditions that can occur between intersections:

- Presence or lack of on-street parking;
- Driveway density or access control;
- Lane additions leading up to, or lane drops leading away from, intersections;
- The impact of grades between intersections;
- Any capacity constraints between intersections (such as a narrow bridge);
- Midblock medians and two-way left-turn lanes;
- Turning movements that exceed 20 percent of the total volume on the street;
- Queues at one intersection backing up to and interfering with the operation of an upstream intersection; and
- Cross-street congestion blocking through traffic.

For queue estimation method, see Chapter 16, Appendix G

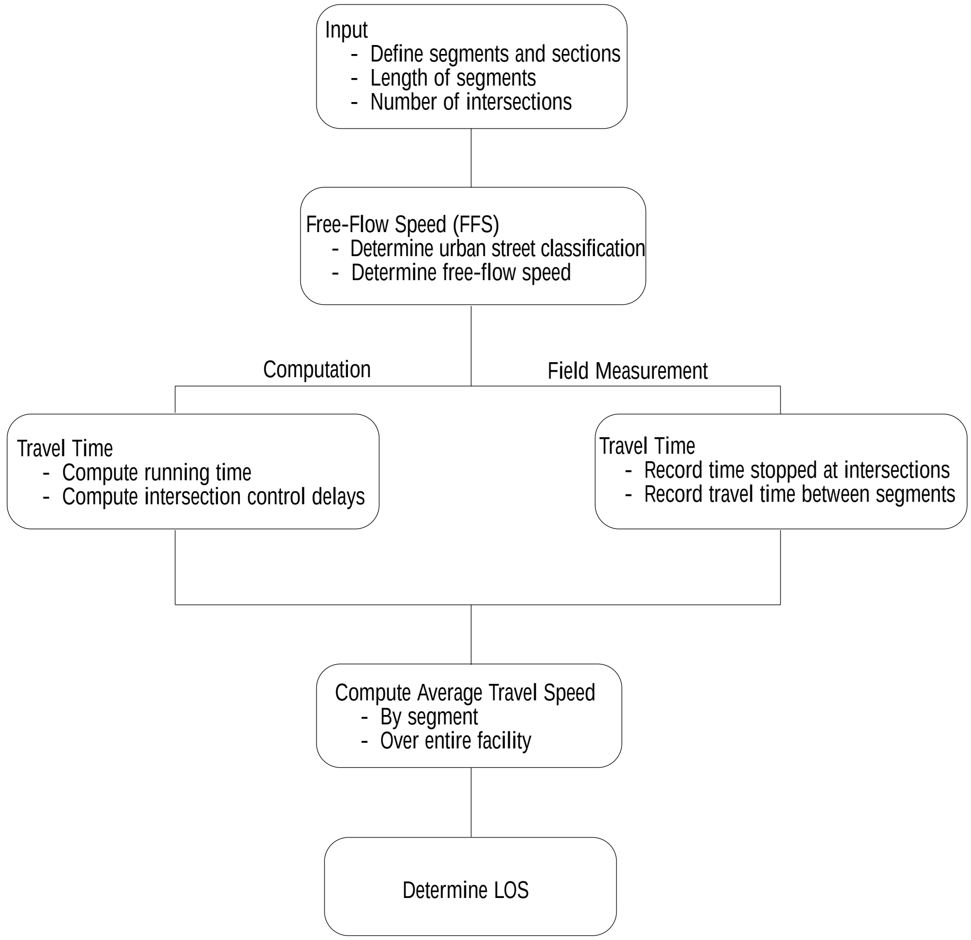
Because any one of these conditions might have a significant impact on the speed of through traffic, the analyst should modify the methodology to incorporate the effects as best as possible.

II. METHODOLOGY

This methodology provides the framework for the evaluation of urban streets. If field data on travel times are available, this framework can be used to determine the street's level of service (LOS). Also, the direct measurement of the travel speed along an urban street can provide an accurate estimate of LOS without using the computations presented in this chapter.

Urban street traffic models can be used as alternative sources for field data, provided that the input parameters—such as running times and saturation flow rates—are determined according to the procedures in this manual, and that the calculated or estimated delay and the delay outputs are based on the definitions and equations in this manual or have been validated by field data. Exhibit 15-1 illustrates the basic method for determining LOS on an urban street.

EXHIBIT 15-1. URBAN STREET METHODOLOGY



The analyst should be able to investigate the effect of signal spacing, street classification, and traffic flow on LOS. The methodology uses the signalized intersection procedure presented in Chapter 16 for the through-traffic lane group. By redefining the lane arrangement (e.g., presence or absence of left-turn lanes, number of lanes), the analyst can influence which traffic flow is in the through-traffic lane group as well as the capacity of the lane group. This redefinition, in turn, influences the street LOS by changing the intersection evaluation and possibly the street classification.

LOS

Urban street LOS is based on average through-vehicle travel speed for the segment or for the entire street under consideration. Travel speed is the basic service measure for urban streets. The average travel speed is computed from the running times on the urban street and the control delay of through movements at signalized intersections.

Control delay

The control delay is the portion of the total delay for a vehicle approaching and entering a signalized intersection that is attributable to traffic signal operation. Control delay includes the delays of initial deceleration, move-up time in the queue, stops, and re-acceleration.

Through vehicles

The LOS for urban streets is influenced both by the number of signals per kilometer and by the intersection control delay. Inappropriate signal timing, poor progression, and increasing traffic flow can degrade the LOS substantially. Streets with medium-to-high signal densities (i.e., more than one signal per kilometer) are more susceptible to these factors, and poor LOS might be observed even before significant problems occur. On the other hand, longer urban street segments comprising heavily loaded intersections can provide reasonably good LOS, although an individual signalized intersection might be operating at a lower level. The term through vehicle refers to all vehicles passing directly through a street segment and not turning.

Exhibit 15-2 lists urban street LOS criteria based on average travel speed and urban street class. It should be noted that if demand volume exceeds capacity at any point on the facility, the average travel speed might not be a good measure of the LOS. The street classifications identified in Exhibit 15-2 are defined in the next section.

Travel speed defines LOS on urban streets

EXHIBIT 15-2. URBAN STREET LOS BY CLASS

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56–72	> 46–59	> 39–50	> 32–41
C	> 40–56	> 33–46	> 28–39	> 23–32
D	> 32–40	> 26–33	> 22–28	> 18–23
E	> 26–32	> 21–26	> 17–22	> 14–18
F	≤ 26	≤ 21	≤ 17	≤ 14

DETERMINING URBAN STREET CLASS

The first step in the analysis is to determine the urban street's class. This can be based on direct field measurement of the FFS or on an assessment of the subject street's functional and design categories. A procedure for measuring the FFS is described in Appendix B.

If the FFS measurements are not available, the street's functional and design categories must be used to identify its class. The functional category is identified first, followed by the design category. This identification uses the definitions provided in Chapter 10 and Exhibit 10-4. After determining the functional and design categories, the urban street class can be established using Exhibit 10-3.

DETERMINING RUNNING TIME

Running time is estimated using FFS, urban street classification, and arterial segment length

There are two principal components of the total time that a vehicle spends on a segment of an urban street: running time and control delay at signalized intersections. To compute the running time for a segment, the analyst must know the street's classification, its segment length, and its FFS. The segment running time then can be found by using Exhibit 15-3.

Within each urban street class there are several influences on actual running time. Exhibit 15-3 shows the effect of street length. In addition, the presence of parking, side friction, local development, and street use can affect running time. In this chapter, these also are assumed to influence the FFS. Direct observation of the FFS, therefore, includes the effect of these factors and, by implication, their effect on the running speed.

If it is not possible to observe the FFS on the actual or a comparable facility, default values are given in a note to Exhibit 15-3.

DETERMINING DELAY

Computing the urban street or section speed requires the intersection control delays. Because the function of an urban street is to serve through traffic, the lane group for through traffic is used to characterize the urban street.

EXHIBIT 15-3. SEGMENT RUNNING TIME PER KILOMETER

Urban Street Class	I			II			III		IV		
FFS (km/h)	90[a]	80[a]	70[a]	70[a]	65[a]	55[a]	55[a]	50[a]	55[a]	50[a]	40[a]
Average Segment Length (m)	Running Time per Kilometer (s/km)										
100	b	b	b	b	b	b	-	-	-	129	159
200	b	b	b	b	b	b	88	91	97	99	125
400	59	63	67	66	68	75	75	78	77	81	96
600	52	55	61	60	61	67	d	d	d	d	d
800	45	49	57	56	58	65	d	d	d	d	d
1000	44	48	56	55	57	65	d	d	d	d	d
1200	43	47	54	54	57	65	d	d	d	d	d
1400	41	46	53	53	56	65	d	d	d	d	d
1600	40[c]	45[c]	51[c]	51[c]	55[c]	65[c]	d	d	d	d	d

Notes:

a. It is best to have an estimate of FFS. If there is none, use the table above, assuming the following default values:

For Class	FFS (km/h)
I	80
II	65
III	55
IV	45

b. If a Class I or II urban street has a segment length less than 400 m, (a) reevaluate the class and (b) if it remains a distinct segment, use the values for 400 m.

c. For long segment lengths on Class I or II urban streets (1600 m or longer), FFS may be used to compute running time per kilometer. These times are shown in the entries for a 1600-m segment.

d. Likewise, Class III or IV urban streets with segment lengths greater than 400 m should first be reevaluated (i.e., the classification should be confirmed). If necessary, the values above 400 m can be extrapolated.

Although this table does not show it, segment running time depends on traffic flow rates; however, the dependence of intersection delay on traffic flow rate is greater and dominates in the computation of travel speed.

The control delay for the through movement is the appropriate delay to use in an urban street evaluation. In general, the analyst should have this information because the intersections should have been evaluated individually as part of the overall analysis. Equation 15-1 is used to compute control delay. Equations 15-2 and 15-3 are used to compute uniform delay and incremental delay, respectively.

$$d = d_1(PF) + d_2 + d_3 \qquad (15\text{-}1)$$

$$d_1 = \frac{0.5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1, X)\frac{g}{C}\right]} \qquad (15\text{-}2)$$

$$d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8klX}{cT}}\right] \qquad (15\text{-}3)$$

where

d = control delay (s/veh);

d_1 = uniform delay (s/veh);

d_2 = incremental delay (s/veh);

d_3 = initial queue delay, see Chapter 16 (s/veh);

PF = progression adjustment factor (Exhibit 15-5);

X = volume to capacity (v/c) ratio for the lane group (also termed degree of saturation);

C = cycle length (s);

c = capacity of lane group (veh/h);

g = effective green time for lane group (s);

T = duration of analysis period (h);

k = incremental delay adjustment for the actuated control; and
I = incremental delay adjustment for the filtering or metering by upstream signals.

Uniform Delay

The v/c ratio (X) for a lane group cannot be greater than 1.0 to compute uniform delay

Equation 15-2 gives an estimate of control delay assuming perfectly uniform arrivals and a stable flow. It is based on the first term of Webster's delay formulation and is accepted as an accurate depiction of delay for the ideal case of uniform arrivals. Values of X greater than 1.0 are not used in the computation of d_1.

Incremental Delay

Equation 15-3 estimates the incremental delay due to nonuniform arrivals and individual cycle failures (i.e., random delay) as well as delay caused by sustained periods of oversaturation (i.e., oversaturation delay). The equation interrelates the degree of saturation (X) of the lane group, the duration of the analysis (T), the capacity of the lane group (c), and the signal control (k). The equation assumes that all demand flow has been serviced in the previous analysis period—that is, there is no initial queue. If there is, Appendix F of Chapter 16 offers procedures to account for the effect of an initial queue. The incremental delay term is valid for all degrees of saturation.

Initial Queue Delay

See also Appendix F of Chapter 16

When a queue from the previous period is present at the start of the analysis, newly arriving vehicles experience initial queue delay. This delay results from the additional time required to clear the initial queue. Its magnitude depends on the size of the initial queue, the length of the analysis period, and the v/c ratio for that period. A procedure for determining the initial queue delay also is described in Appendix F of Chapter 16.

Arrival Type and Platoon Ratio

A critical characteristic that must be quantified for the analysis of an urban street or signalized intersection is the quality of the progression. The parameter that describes this characteristic is the arrival type, AT, for each lane group. This parameter approximates the quality of progression by defining six types of dominant arrival flow.

Six arrival types

Arrival Type 1 is characterized by a dense platoon of more than 80 percent of the lane group volume arriving at the start of the red phase. This arrival type represents network links that experience a poor rate of progression due to various conditions, including lack of coordination.

Arrival Type 2 is characterized by a moderately dense platoon that arrives in the middle of the red phase or by a dispersed platoon of 40 to 80 percent of the lane group volume arriving throughout the red phase. This arrival type represents an unfavorable progression along an urban street.

Arrival Type 3 consists of random arrivals in which the main platoon contains less than 40 percent of the lane group volume. This arrival type represents operations at noninterconnected, signalized intersections with highly dispersed platoons. It also may be used to represent a coordinated operation with minimal benefits of progression.

Arrival Type 4 consists of a moderately dense platoon that arrives in the middle of the green phase or of a dispersed platoon of 40 to 80 percent of the lane group volume arriving throughout the green phase. This arrival type represents a favorable progression along an urban street.

Arrival Type 5 is characterized by a dense to moderately dense platoon of more than 80 percent of the lane group volume arriving at the start of the green phase. This arrival type represents a highly favorable progression, which may occur on routes with a low-to-moderate number of side street entries and which receive high priority in signal timing.

Arrival Type 6 is reserved for exceptional progression quality on routes with near-ideal characteristics. It represents dense platoons progressing over several closely spaced intersections with minimal or negligible side street entries.

Arrival type is best observed in the field but can be approximated by examining time-space diagrams for the street. The arrival type should be determined as accurately as possible because it has a significant impact on delay estimates and LOS determination. Although there are no definitive parameters to quantify arrival type, the ratio defined by Equation 15-4 is useful.

$$R_p = P\left(\frac{C}{g}\right) \qquad (15\text{-}4)$$

where

- R_P = platoon ratio,
- P = proportion of all vehicles arriving during green,
- C = cycle length (s), and
- g = effective green time for movement (s).

The value for P may be estimated or observed in the field, whereas C and g are computed from the signal timing. The value of P may not exceed 1.0. The approximate ranges of R_p relate to arrival type as shown in Exhibit 15-4, which also suggests default values for use in subsequent computations.

EXHIBIT 15-4. RELATIONSHIP BETWEEN ARRIVAL TYPE AND PLATOON RATIO (R_p)

Arrival Type	Range of Platoon Ratio (R_p)	Default Value (R_p)	Progression Quality
1	≤ 0.50	0.333	Very poor
2	> 0.50–0.85	0.667	Unfavorable
3	> 0.85–1.15	1.000	Random arrivals
4	> 1.15–1.50	1.333	Favorable
5	> 1.50–2.00	1.667	Highly favorable
6	> 2.00	2.000	Exceptional

Progression Adjustment Factor

Good signal progression results in the arrival of a high proportion of vehicles on the green; poor signal progression results in the arrival of a low proportion of vehicles on the green. The progression adjustment factor, PF, applies to all coordinated lane groups, whether the control is pretimed or nonactuated in a semiactuated system. Progression primarily affects uniform delay; for this reason, the adjustment is applied only to d_1. The value of PF may be determined by Equation 15-5.

$$PF = \frac{(1-P)f_{PA}}{\left(1-\frac{g}{C}\right)} \qquad (15\text{-}5)$$

where

- PF = progression adjustment factor,
- P = proportion of all vehicles arriving during green,
- g/C = effective green-time ratio, and
- f_{PA} = supplemental adjustment factor for platoon arrival during the green.

The value of P may be measured in the field or estimated from the time-space diagram. The value of PF also may be computed from measured values of P using the default values for f_{PA}. Alternatively, Exhibit 15-5 may be used to determine PF as a function of the arrival type based on the default values for P and f_{PA} associated with each arrival type. If PF is estimated by Equation 15-5, its value may not exceed 1.0 for Arrival

Type 4 with extremely low values of g/C; as a practical matter, PF should be assigned a maximum value of 1.0 for Arrival Type 4.

EXHIBIT 15-5. PROGRESSION ADJUSTMENT FACTORS FOR UNIFORM DELAY CALCULATION

Green Ratio (g/C)	Arrival Type (AT)					
	AT 1	AT 2	AT 3	AT 4	AT 5	AT 6
0.20	1.167	1.007	1.000	1.000	0.833	0.750
0.30	1.286	1.063	1.000	0.986	0.714	0.571
0.40	1.445	1.136	1.000	0.895	0.555	0.333
0.50	1.667	1.240	1.000	0.767	0.333	0.000
0.60	2.001	1.395	1.000	0.576	0.000	0.000
0.70	2.556	1.653	1.000	0.256	0.000	0.000
f_{PA}	1.00	0.93	1.00	1.15	1.00	1.00
Default, R_p	0.333	0.667	1.000	1.333	1.667	2.000

Notes:
PF = $(1 - P)f_{PA}/(1 - g/C)$.
Tabulation is based on default values of f_p and R_p.
$P = R_p * g/C$ (may not exceed 1.0).
PF may not exceed 1.0 for AT 3 through AT 6.

Guidelines on arrival type for future conditions

The progression adjustment factor, PF, requires knowledge of offsets, travel speeds, and intersection signalization. When delay is estimated for future coordination, particularly when analyzing alternatives, Arrival Type 4 should be assumed as a base condition for coordinated lane groups (except for left turns), and Arrival Type 3 should be assumed for all uncoordinated lane groups.

For movements made from exclusive left-turn lanes on exclusive phases, the progression adjustment factor usually should be 1.0 (i.e., Arrival Type 3). However, if the signal coordination provides for a progression of left-turn movements, the progression adjustment factor should be computed from the estimated arrival type, as for through movements. When the coordinated left turn is part of protected-permitted phasing, only the effective green for the protected phase should be used to determine the progression adjustment factor, since the protected phase normally is associated with platooned coordination. A flow-weighted average of P should be used in determining PF when a time-space diagram is used and lane group movements have different levels of coordination.

Incremental Delay Adjustment for Actuated Controls

For pretimed signals, k = 0.50

In Equation 15-3 the term k incorporates the effect of the controller on delay. For pretimed signals, a k-value of 0.50 is used. This is based on queuing with random arrivals and on uniform service equivalent to the lane group capacity. Actuated controllers, however, can tailor the green time to the current demand, reducing the overall incremental delay. The delay reduction depends in part on the controller's unit extension and the degree of saturation. Research has indicated that lower unit extensions (i.e., snappy intersection operation) result in lower values of k and d_2. However, when the degree of saturation approaches 1.0, an actuated controller will act like a pretimed controller, producing k-values of 0.50 at degrees of saturation greater than or equal to 1.0. Exhibit 15-6 illustrates the k-values recommended for actuated controllers with different unit extensions and degrees of saturation.

For unit extension values not listed in Exhibit 15-6, the k-values may be interpolated. If the formula in Exhibit 15-6 is used, the k_{min} value (i.e., the k-value for X = 0.50) first should be interpolated for the unit extension and then the formula should be used. Exhibit 15-6 may be extrapolated for unit extension values beyond 5.0 s, but the extrapolated k-value never should exceed 0.50.

EXHIBIT 15-6. k-VALUE FOR CONTROLLER TYPE

Unit Extension (s)	Degree of Saturation (X)					
	≤ 0.50	0.60	0.70	0.80	0.90	≥ 1.0
≤ 2.0	0.04	0.13	0.22	0.32	0.41	0.50
2.5	0.08	0.16	0.25	0.33	0.42	0.50
3.0	0.11	0.19	0.27	0.34	0.42	0.50
3.5	0.13	0.20	0.28	0.35	0.43	0.50
4.0	0.15	0.22	0.29	0.36	0.43	0.50
4.5	0.19	0.25	0.31	0.38	0.44	0.50
5.0[a]	0.23	0.28	0.34	0.39	0.45	0.50
Pretimed or Nonactuated Movement	0.50	0.50	0.50	0.50	0.50	0.50

Notes:
For a unit extension and its k_{min} value at X = 0.5: $k = (1 - 2k_{min})(X - 0.5) + k_{min}$, where $k \geq k_{min}$, and $k \leq 0.5$.
a. For a unit extension more than > 5.0, extrapolate to find k, keeping k ≤ 0.5.

Upstream Filtering or Metering Adjustment Factor, I

The incremental delay adjustment term I in Equation 15-4 accounts for the effects of filtered arrivals from upstream signals. An I-value of 1.0 is used for an isolated intersection (i.e., one that is 1.6 km or more from the nearest upstream signalized intersection). This value is based on a random number of vehicles arriving per cycle so that the variance in arrivals equals the mean.

An I-value of less than 1.0 is used for nonisolated intersections. This reflects the way that upstream signals decrease the variance in the number of arrivals per cycle at the subject (i.e., downstream) intersection. As a result, the amount of delay due to random arrivals is reduced.

Exhibit 15-7 lists I-values for nonisolated intersections. The values of I in this exhibit are based on X_u, the weighted v/c ratio of all upstream movements contributing to the volume in the subject intersection lane group. This ratio is computed as a weighted average with the v/c ratio of each contributing upstream movement weighted by its volume. For the analysis of urban street performance, it is sufficient to approximate X_u as the v/c ratio of the upstream through movement.

EXHIBIT 15-7. RECOMMENDED I-VALUES FOR LANE GROUPS WITH UPSTREAM SIGNALS

	Degree of Saturation at Upstream Intersection, X_u						
	0.40	0.50	0.60	0.70	0.80	0.90	≥ 1.0
I	0.922	0.858	0.769	0.650	0.500	0.314	0.090

Note: $I = 1.0 - 0.91\, X_u^{2.68}$ and $X_u \leq 1.0$.

DETERMINING TRAVEL SPEED

Equation 15-6 is used on each segment and on the entire section to compute the travel speed.

$$S_A = \frac{3600L}{T_R + d} \qquad (15\text{-}6)$$

where

S_A = average travel speed of through vehicles in the segment (km/h);
L = segment length (km);
T_R = total of running time on all segments in defined section (s); and
d = control delay for through movements at the signalized intersection (s).

Other delay can be an additional term in the denominator of Equation 15-6

In special cases, there might be midblock delays caused by vehicle stops at pedestrian crosswalks, or other delays caused by bus stops or driveways. These other delays can be added to the denominator of Equation 15-6.

DETERMINING LOS

There is a distinct set of urban street LOS criteria for each urban street class. These criteria are based on the differing expectations that drivers have for the different kinds of urban streets. Both the FFS of the urban street class and the intersection LOS definitions are taken into account. Exhibit 15-2 gives the LOS criteria for each urban street class. These criteria vary with the class: the lesser the urban street (i.e., the higher its classification number), the lower the driver's expectation for that facility and the lower the speed associated with the LOS. Thus, a Class III urban street provides LOS B at a lower speed than a Class I urban street.

The analyst should be aware of this in explaining before-and-after assessments of urban streets that have been upgraded. If reconstruction upgrades a facility from Class II to Class I, it is possible that the LOS will not change (or may even decline), despite the higher average speed and other improvements, because the expectations would be higher.

The concept of overall urban street LOS is meaningful only when all segments on the urban street are in the same class.

SENSITIVITY OF RESULTS TO INPUT VARIABLES

The following speed-flow curves illustrate the sensitivity of travel speed to

- FFS,
- v/c ratio,
- Signal density, and
- Urban street class.

Exhibits 15-8 through 15-11 use the v/c ratio to plot the through movement in the peak direction at the critical intersection on an urban street. The critical intersection is the intersection with the highest through v/c ratio. The through capacity of an intersection on the urban street is computed using Equation 15-7.

$$c = N * s * \frac{g}{C} \tag{15-7}$$

where

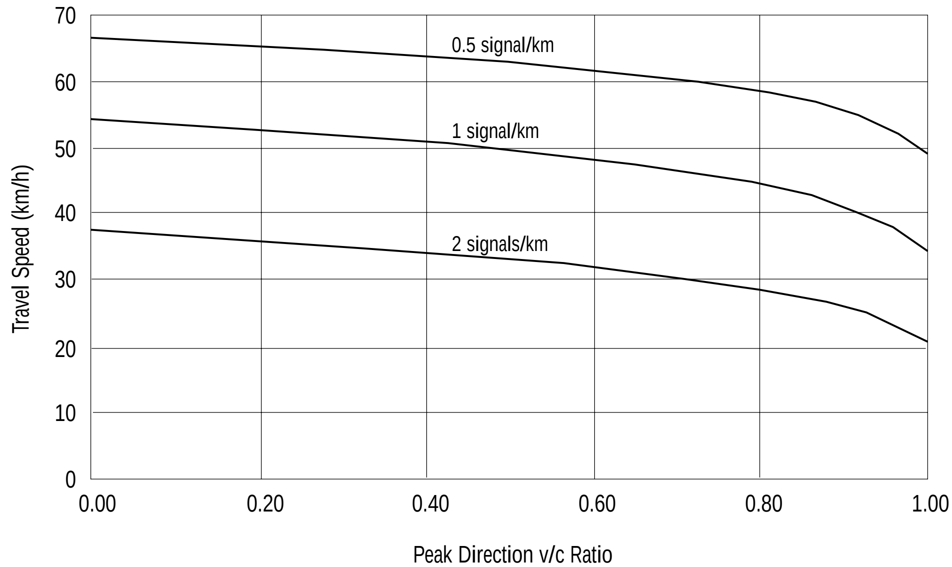
c = capacity of the through lane (veh/h),
N = number of through lanes at the intersection,
s = adjusted saturation flow per through lane (veh/h), and
g/C = effective green time per cycle for the through movement at the intersection.

The capacity of an urban street is defined for a single direction of travel as the capacity of the through movement at its lowest point (usually at a signalized intersection). The capacity is determined by the number of lanes, the saturation flow rate per lane (influenced by geometric design and demand factors), and the green time per cycle for the through movement at the intersection.

The cycle length also can affect the urban street capacity. Longer cycle lengths generally allow a greater portion of the available green time for the through movement, but still provide for pedestrian clearance times, phase-change intervals, and vehicle clearance times.

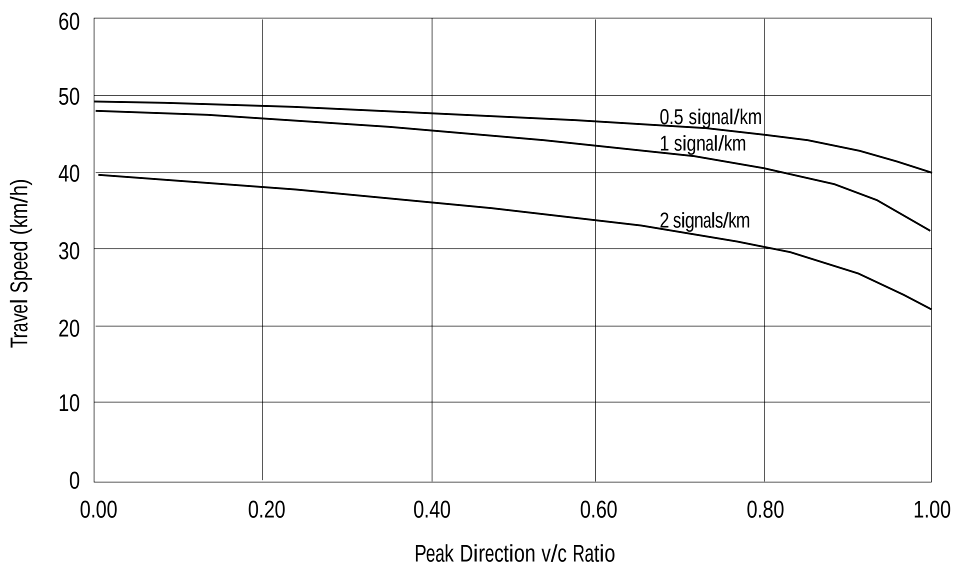
Signal coordination (i.e., the quality of progression) generally improves urban street speeds and LOS. Improved coordination, however, does not generally increase urban street capacity by itself—the g/C ratio for the major street also must be improved by the coordination plan.

EXHIBIT 15-8. SPEED-FLOW CURVES FOR CLASS I URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 80-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

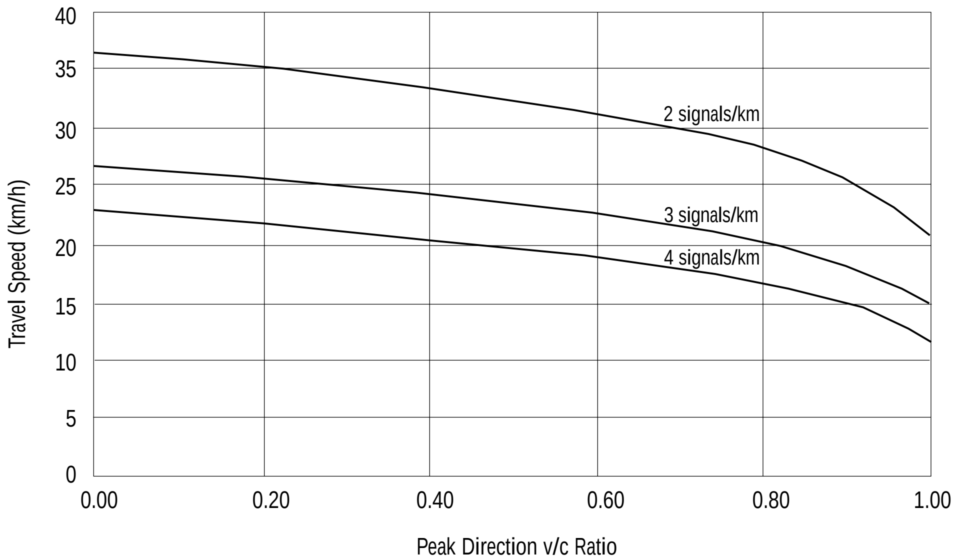
EXHIBIT 15-9. SPEED-FLOW CURVES FOR CLASS II URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 65-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

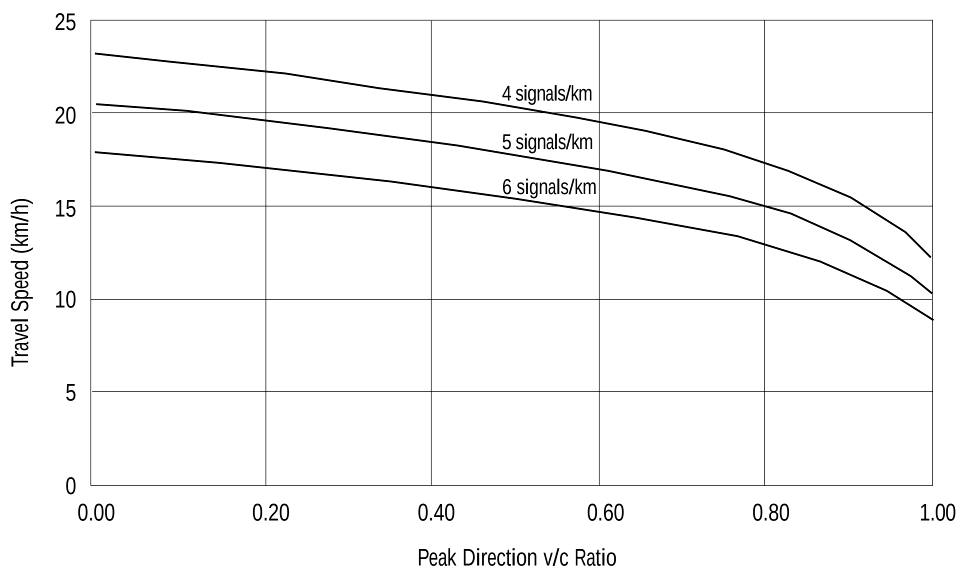
Increased signal density generally lowers urban street speeds and LOS but does not affect capacity, unless the added signals have lower g/C ratios, or lower saturation flow rates, for the through movements.

EXHIBIT 15-10. SPEED-FLOW CURVES FOR CLASS III URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 55-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

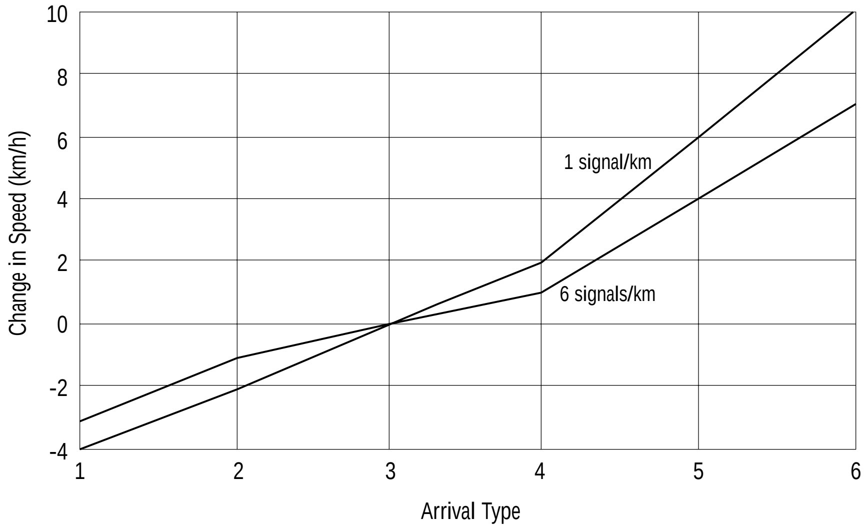
EXHIBIT 15-11. SPEED-FLOW CURVES FOR CLASS IV URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 50-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 4, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

Exhibits 15-8, 15-9, 15-10, and 15-11 show how signal density and intersection v/c ratios for urban street through movements affect the mean travel speeds for the different street classes. The signal timing and street design assumptions used in computing these specific curves are listed as footnotes. For computational convenience, it was assumed that all signals on each street had identical demand, signal timing, and geometric characteristics. Different assumptions would yield different curves. Exhibit 15-12 illustrates the sensitivity of estimated speed to arrival types.

EXHIBIT 15-12. CHANGE IN MEAN SPEED FOR ARRIVAL TYPES
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: Urban street Class III, 56-km/h midblock FFS, 10-km length, 120-s cycle, 0.45 g/C, pretimed signals, 0.925 peak-hour factor (PHF), exclusive left-turn lanes, 12 percent left turns.

III. APPLICATIONS

For guidelines on required inputs and estimated values, see Chapter 10

To apply the methodology, two fundamental questions must be addressed.

• First, what is the primary output? Typically, it includes LOS and achievable flow rate (v_p). Performance measures related to control delay and travel speed also are achievable but are considered secondary outputs.

• Second, what are the default values or estimated values to be used in the analysis?

Basically, there are three sources of input data:

1. Default values found in this manual,
2. Estimates and locally derived default values developed by the analyst, and
3. Values derived from field measurements and observation.

For each of the input variables, a value must be supplied to calculate the outputs, both primary and secondary.

A common application of the method is to compute the LOS of a current or changed facility for the near term or distant future. This type of application is often termed operational; its primary output is LOS, with secondary outputs for delay and speed.

Another type of application solves for the service flow rate, v_p, as the primary output, to determine when improvements are required. This analysis must state as inputs a LOS goal and a number of lanes. Typically it is used to estimate the maximum flow rate that can be accommodated while still providing a given LOS.

Another type of application, planning, uses estimates, HCM default values, and local default values as inputs. As outputs, planning applications can determine LOS or flow rate along with delay and speed as secondary outputs. The difference between planning analysis and operational or design analysis is that most or all of the input values for planning come from estimates or default values, but the operational applications tend to use field-measured or known values for most or all of the inputs. For each of the analyses, FFS—either measured or estimated—is required as an input.

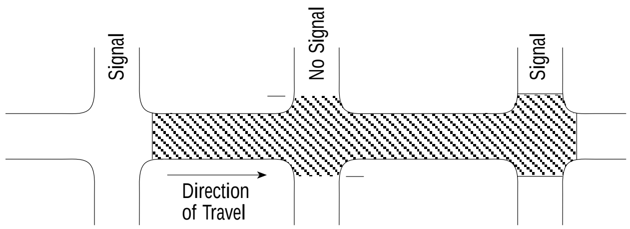
SEGMENTING THE URBAN STREET

Guidelines on the length of a facility for analysis

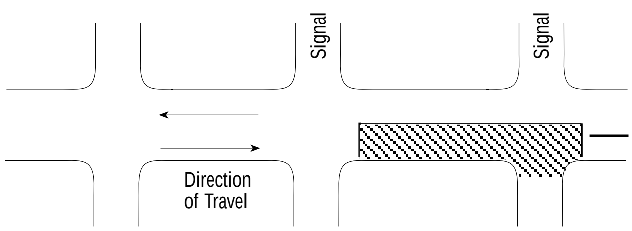
At the start of the analysis, the location and length of the urban street to be considered must be defined. All relevant physical, signal, and traffic data should be identified. Consideration should be given to the extent of the urban street—generally at least 1.5 km is necessary in downtown areas and 3.0 km in other areas—and to whether additional segments should be included.

The segment is the basic unit of the analysis; it is a one-directional distance from one signalized intersection to the next. Exhibit 15-13 illustrates the segment concept on one- and two-way streets.

EXHIBIT 15-13. TYPES OF URBAN STREET SEGMENTS



(a) Segment on a One-Way Street



(b) Segment on a Two-Way Street

COMPUTATIONAL STEPS

The worksheet for computations is shown in Exhibit 15-14. A completed worksheet documents the analysis for one travel direction along the street. To understand the operation of the entire urban street facility, it is necessary to apply the methodology twice—once in each direction, to assess the LOS of each.

Operational (LOS) application

The first step for an operational (LOS) application is to establish the location and length of the urban street. Then the street class is determined, using Exhibit 10-3. FFS also is determined. The next step is to divide the street into segments. Running time is computed for each segment, along with control delay for the through movements at each intersection. Average travel speed is computed by segment and for the entire facility. Using the average travel speed, the LOS is determined by referring to Exhibit 15-2.

Design (v_p) application

The objective of design analysis for flow rate, v_p, is to estimate the flow rate in vehicles per hour using an adjusted saturation flow rate, signal timing data, and geometric data for the urban street. A desired LOS is set at the start of the analysis and used to obtain the lowest acceptable average travel speed shown in Exhibit 15-2. The delay for each intersection is determined with the equation for urban street travel speed. By backsolving the delay equation, the v/c ratio, X, is computed. From X, the maximum service flow rate, v_p, is determined for the desired LOS.

EXHIBIT 15-14. URBAN STREET WORKSHEET

URBAN STREET WORKSHEET

General Information | **Site Information**

Analyst ____________ | Urban Street ____________
Agency or Company ____________ | Direction of Travel ____________
Date Performed ____________ | Jurisdiction ____________
Analysis Time Period ____________ | Analysis Year ____________

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p) Analysis Period, T =_______ h

Input Parameters

	Segments							
	1	2	3	4	5	6	7	8
Cycle length, C (s)								
Effective green-to-cycle-length ratio, g/C								
v/c ratio for lane group, X								
Capacity of lane group, c (veh/h)								
Arrival type, AT								
Length of segment, L (km)								
Initial queue, Q_b (veh)								
Urban street class, SC (Exhibit 10-3)								
Free-flow speed, FFS (km/h) (Exhibit 15-2)								
Running time, T_R (s) (Exhibit 15-3)								
Delay Computation								
Uniform delay, d_1 (s) $d_1 = \frac{0.5C[(1 - g/C)^2]}{1 - [(g/C)\min(X, 1.0)]}$								
Signal control adjustment factor, k (Exhibit 15-6)								
Upstream filtering/metering adjustment factor, I (Exhibit 15-7)								
Incremental delay, d_2 (s) $d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right]$								
Initial queue delay, d_3 (s) (Ch. 16 Appendix F)								
Progression adjustment factor, PF (Exhibit 15-5)								
Control delay, d (s) $d = (d_1 * PF) + d_2 + d_3$								
Segment LOS Determination								
Segment travel time, ST (s) $ST = T_R + d + \text{Other delay}$								
Segment travel speed, S_A (km/h) $S_A = \frac{3600(L)}{ST}$								
Segment LOS (Exhibit 15-2)								

Urban Street LOS Determination

Total travel time = $\sum ST$ ________________s
Total length = $\sum L$ ________________km
Total travel speed, $S_A = \frac{3600 * \text{Total length}}{\text{Total travel time}}$ ________________km/h
Total urban street LOS (Exhibit 15-2) ________________

PLANNING APPLICATIONS

The objective of an urban street LOS analysis at a planning level is to estimate the operating conditions of the facility. An important use for this type of analysis is to address growth management. The accuracy of a planning LOS analysis depends on the input data. It is most appropriate when estimates of LOS are desired, field data are lacking, and planning horizons are longer.

Simplifying assumptions about left turns for planning applications

A major difference between the planning analysis of signalized intersections and that of urban streets is the treatment of turning vehicles. Because the analysis of an urban street emphasizes through movement, the simplifying assumption is that left turns are accommodated by left-turn bays at major intersections and by controls with a properly timed separate phase. As a result, many of the inputs and complexities of intersection analyses can be simplified by using default values.

Planning (LOS) and planning (v_p) applications

The two planning applications, planning (LOS) and planning (v_p) directly correspond to the procedures described for operational (LOS) and design (v_p), respectively, in the previous section.

For computational steps in planning applications, see Appendix A

The first criterion that categorizes planning applications is the use of estimates, HCM default values, or local default values on the input side of the calculation. Another factor that defines an application as planning is the use of annual average daily traffic (AADT) to estimate directional design-hour volume (DDHV). DDHV is calculated using a known or forecasted value of K (the proportion of AADT occurring during the peak hour) and D (the proportion of two-way traffic in the peak direction), as shown in Chapter 8. For further guidelines on selecting K and D values, refer to Chapter 8. The computational steps of planning applications are described in Appendix A.

To perform planning applications, typically few, if any, of the required input values must be measured. Chapter 10 contains more information on the use of default values. Planning applications based on the methodology of this chapter assume that left turns are accommodated by separate lanes and phases and therefore have minimal effect on through vehicles.

For planning purposes, FFS should be based on actual studies of the street or on studies of similar streets and should be consistent with urban street classifications. The actual or probable posted speed limit may be used as a surrogate for FFS if field data are not available.

ANALYSIS TOOLS

The worksheet shown in Exhibit 15-14 and provided in Appendix C can be used for all applications.

IV. EXAMPLE PROBLEMS

Problem No.	Description	Application
1	Find LOS for a 3.5-km divided multilane urban street	Operational (LOS)
2	Find LOS for a 4.0-km urban street for a range of flow rates	Operational (LOS), Design (v_p)
3	Find LOS of a divided urban street with field-collected data	Operational (LOS)
4	Find LOS for a proposed divided urban street	Planning (LOS)
5	Find maximum service flow rates and AADT for a desired LOS	Planning (v_p)

EXAMPLE PROBLEM 1

The Urban Street The total length of a divided multilane urban street is 3.5 km, with seven signalized intersections at 0.5-km spacing.

The Question What is the LOS by segment and for the entire length for one direction of flow for through lane groups?

The Facts

- √ Field-measured FFS = 63 km/h,
- √ Cycle length = 70 s (all signals),
- √ Lane group capacity = 1,800 veh/h,
- √ v/c ratio as shown on the worksheet,
- √ Analysis period = 1.0 h,
- √ Urban street Class II,
- √ g/C = 0.60 (all through lane groups),
- √ Arrival Type 3 for Segment 1,
- √ Arrival Type 5 for all other segments, and
- √ Pretimed signals.

Outline of Solution All input parameters are known and no default values are required. Compute delay at signalized intersections. Then compute urban street speed and LOS for each segment and for the entire street. Since no signal progression and no traffic filtering or metering takes place upstream of the first signal, assume that its PF = 1.0 and I = 1.0. The following steps describe computations for the first segment and the entire length for one direction of flow.

Steps

1. Find factors PF, k, and I to compute control delay (use Exhibits 15-5, 15-6, and 15-7).	PF = 0.0, k = 0.50, and I as calculated in Exhibit 15-7
2. Find d_1 (use Equation 15-2).	$d_1 = \frac{0.5C\left[\left(1-\frac{g}{C}\right)^2\right]}{\left[1-\left(\frac{g}{C}\right)\min(X,1.0)\right]}$ $d_1 = \frac{0.5*70[(1-0.60)^2]}{[1-0.60(0.583)]} = 8.6 \text{ s}$
3. Find d_2 (use Equation 15-3).	$d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}}\right]$ $d_2 = 900(1)\left[(0.583-1)+\sqrt{(0.583-1)^2+\frac{8*0.5*1.0*0.583}{1,800(1)}}\right]$ d_2 = 1.4 s
4. Find d (use Equation 15-1).	d = (d_1 * PF) + d_2 + d_3 = (8.6 * 1.0) + 1.4 + 0.0 = 10.0 s
5. Find running time (use Exhibit 15-3).	For FFS = 63 km/h, running time per km = 65.8 s/km T_R = 65.8 * 0.5 = 32.9 s (for all segments)
6. Find travel time	ST = T_R + d + other d = 32.9 + 10.0 + 0.0 = 42.9 s
7. Find S_A (use Equation 15-6).	$S_A = \frac{3,600(L)}{ST} = \frac{3,600(0.5)}{42.9} = 42.0 \text{ km/h}$
8. Determine LOS (use Exhibit 15-2).	LOS C
9. Find S_A for the entire urban street (use Equation 15-6).	$\sum ST$ = 42.9 + 3(34.0) + 3(34.1) = 247.2 s $\sum L$ = 7(0.5) = 3.5 km Urban street $S_A = \frac{3,600*\sum L}{\sum ST} = \frac{3,600(3.5)}{247.2} =$ 51.0 km/h

10. Determine urban street LOS (use Exhibit 15-2).	LOS B

Results Urban street LOS = B.

Example Problem 1

URBAN STREET WORKSHEET

General Information		**Site Information**	
Analyst	JMYE	Urban Street	Multilane Urban
Agency or Company	CEI	Direction of Travel	SB
Date Performed	5/7/99	Jurisdiction	
Analysis Time Period	AM Peak	Analysis Year	1999

☒ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p) Analysis Period, T = 1.00 h

Input Parameters

	Segments							
	1	2	3	4	5	6	7	8
Cycle length, C (s)	70	70	70	70	70	70	70	
Effective green-to-cycle-length ratio, g/C	0.60	0.60	0.60	0.60	0.60	0.60	0.60	
v/c ratio for lane group, X	0.583	0.611	0.611	0.611	0.597	0.593	0.593	
Capacity of lane group, c (veh/h)	1,800	1,800	1,800	1,800	1,800	1,800	1,800	
Arrival type, AT	3	5	5	5	5	5	5	
Length of segment, L (km)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Initial queue, Q_b (veh)	-	-	-	-	-	-	-	
Urban street class, SC (Exhibit 10-3)	II	II	II	II	II	II	II	
Free-flow speed, FFS (km/h) (Exhibit 15-2)	63	63	63	63	63	63	63	
Running time, T_R (s) (Exhibit 15-3)	32.9	32.9	32.9	32.9	32.9	32.9	32.9	

Delay Computation

	1	2	3	4	5	6	7	8
Uniform delay, d_1 (s) $d_1 = \frac{0.5C[(1-g/C)^2]}{1-[(g/C)\min(X, 1.0)]}$	8.6	8.8	8.8	8.8	8.7	8.7	8.7	
Signal control adjustment factor, k (Exhibit 15-6)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
Upstream filtering/metering adjustment factor, I (Exhibit 15-7)	1.0	0.786	0.757	0.757	0.757	0.772	0.776	
Incremental delay, d_2 (s) $d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}}\right]$	1.4	1.2	1.2	1.2	1.1	1.1	1.1	
Initial queue delay, d_3 (s) (Ch. 16 Appendix F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Progression adjustment factor, PF (Exhibit 15-5)	1.0	0.0	0.0	0.0	0.0	0.0	0.0	
Control delay, d (s) $d = (d_1 * PF) + d_2 + d_3$	10.0	1.2	1.2	1.2	1.1	1.1	1.1	

Segment LOS Determination

	1	2	3	4	5	6	7	8
Segment travel time, ST (s) $ST = T_R + d +$ Other delay	42.9	34.1	34.1	34.1	34.0	34.0	34.0	
Segment travel speed, S_A (km/h) $S_A = \frac{3600(L)}{ST}$	42.0	52.8	52.8	52.8	52.9	52.9	52.9	
Segment LOS (Exhibit 15-2)	C	B	B	B	B	B	B	

Urban Street LOS Determination

Total travel time = $\sum ST$	247.2	s
Total length = $\sum L$	3.5	km
Total travel speed, $S_A = \frac{3600 * \text{Total length}}{\text{Total travel time}}$	51.0	km/h
Total urban street LOS (Exhibit 15-2)	B	

EXAMPLE PROBLEM 2

The Urban Street A two-lane urban street with five intersections at various spacings as shown in the worksheet. The street experiences high left-turn volume, served by a permitted phase and an exclusive turn lane.

The Question What is the LOS by segment and for the entire facility?

The Facts

- √ Field-measured FFS = 50 km/h,
- √ Cycle length = 90 s,
- √ Lane group capacity = 1,650 veh/h,
- √ Arrival Type 3,
- √ Analysis period = 0.25 h,
- √ Urban street Class IV,
- √ g/C ratio as shown on the worksheet,
- √ Initial queue at Intersection 4 = 22 veh,
- √ Pretimed signals, and
- √ v/c ratio as shown on the worksheet.

Outline of Solution All input parameters are known and no default values are required. The volume at Signal 5 is affected by upstream metering at oversaturated Signal 4. Since the conditions are oversaturated, no volume adjustment at Signal 5 is needed. Delay at signalized intersections is computed, including the effect of the initial queue at Signal 4 at the start of the analysis period. The urban street speed is computed and LOS is determined. The following steps describe computations for Signal 4.

Steps

1. Find PF, k, and I (use Exhibits 15-5, 15-6, and 15-7).	PF = 1.0, k = 0.50, I = 0.145
2. Find d_1 (use Equation 15-2).	$d_1 = \dfrac{0.5C\left[\left(1-\dfrac{g}{C}\right)^2\right]}{\left[1-\left(\dfrac{g}{C}\right)\min(X,1.0)\right]}$ $d_1 = \dfrac{0.5*90[(1-0.566)^2]}{[1-0.566(1.0)]} = 19.5\text{ s}$
3. Find d_2 (use Equation 15-3).	$d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\dfrac{8kIX}{cT}}\right]$ $d_2 = 900(0.25)\left[(1.105-1)+\sqrt{(1.105-1)^2+\dfrac{8*0.5*0.145*1.105}{1,650(0.25)}}\right]$ d_2 = 48.9 s
4. Find d_3 (refer to Ch. 16 Appendix F, Case V).	$d_3 = \dfrac{1,800Q_b(1+u)t}{cT}$ $d_3 = \dfrac{1,800*22*(1+1)*0.25}{1,650*0.25} = 48.0\text{ s}$
5. Find d (use Equation 15-1).	d = (d_1 * PF) + d_2 + d_3 d = (19.5 * 1.0) + 48.9 + 48.0 = 116.4 s
6. Find running time for Segment 4 length of 500 m (use Exhibit 15-3).	For FFS = 50 km/h, running time per km = 81.0 s/km T_R = 81.0 * 0.5 = 40.5 s
7. Find S_A for Segment 4 (use Equation 15-6).	$S_A = \dfrac{3,600(L)}{T_R+d} = \dfrac{3,600(0.5)}{40.5+116.4} =$ 11.4 km/h
8. Determine LOS for the segment (use Exhibit 15-2).	LOS F (Segment 4)

9. Determine entire urban street LOS (use Exhibit 15-2).	LOS D

Results

- For fourth section, LOS F; and
- For urban street, LOS D.

Example Problem 2

URBAN STREET WORKSHEET

General Information		**Site Information**	
Analyst	*JMYE*	Urban Street	*Park Ave.*
Agency or Company	*CEI*	Direction of Travel	*WB*
Date Performed	*5/7/99*	Jurisdiction	
Analysis Time Period	*PM Peak*	Analysis Year	*1999*

☒ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p) Analysis Period, T = *0.25* h

Input Parameters

	Segments							
	1	2	3	4	5	6	7	8
Cycle length, C (s)	*90*	*90*	*90*	*90*	*90*			
Effective green-to-cycle-length ratio, g/C	*0.289*	*0.566*	*0.467*	*0.566*	*0.600*			
v/c ratio for lane group, X	*0.822*	*0.951*	*0.977*	*1.105*	*0.456*			
Capacity of lane group, c (veh/h)	*1,650*	*1,650*	*1,650*	*1,650*	*1,650*			
Arrival type, AT	*3*	*3*	*3*	*3*	*3*			
Length of segment, L (km)	*0.4*	*0.4*	*0.4*	*0.5*	*0.3*			
Initial queue, Q_b (veh)	-	-	-	*22*	-			
Urban street class, SC (Exhibit 10-3)	*IV*	*IV*	*IV*	*IV*	*IV*			
Free-flow speed, FFS (km/h) (Exhibit 15-2)	*50*	*50*	*50*	*50*	*50*			
Running time, T_R (s) (Exhibit 15-3)	*32.4*	*32.4*	*32.4*	*40.5*	*27.0*			
Delay Computation								
Uniform delay, d_1 (s) $d_1 = \frac{0.5C[(1-g/C)^2]}{1-[(g/C)\min(X, 1.0)]}$	*29.8*	*18.4*	*23.5*	*19.5*	*9.9*			
Signal control adjustment factor, k (Exhibit 15-6)	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*			
Upstream filtering/metering adjustment factor, I (Exhibit 15-7)	*1.0*	*0.462*	*0.205*	*0.145*	*0.090*			
Incremental delay, d_2 (s) $d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}}\right]$	*4.8*	*7.3*	*6.0*	*48.9*	*0.1*			
Initial queue delay, d_3 (s) (Ch. 16 Appendix F)	*0.0*	*0.0*	*0.0*	*48.0*	*0.0*			
Progression adjustment factor, PF (Exhibit 15-5)	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*			
Control delay, d (s) $d = (d_1 * PF) + d_2 + d_3$	*34.6*	*25.7*	*29.5*	*116.4*	*10.0*			
Segment LOS Determination								
Segment travel time, ST (s) $ST = T_R + d + \text{Other delay}$	*67.0*	*58.1*	*61.9*	*157.3*	*37.0*			
Segment travel speed, S_A (km/h) $S_A = \frac{3600(L)}{ST}$	*21.5*	*24.8*	*23.3*	*11.4*	*29.2*			
Segment LOS (Exhibit 15-2)	*D*	*C*	*C*	*F*	*C*			

Urban Street LOS Determination

Total travel time = $\sum ST$	*381.8*	s
Total length = $\sum L$	*2.0*	km
Total travel speed, $S_A = \frac{3600 * \text{Total length}}{\text{Total travel time}}$	*18.9*	km/h
Total urban street LOS (Exhibit 15-2)	*D*	

EXAMPLE PROBLEM 3

The Urban Street A multilane two-way divided suburban street with left-turn bays and eight signalized intersections.

The Question What is the LOS by segment and for the entire facility?

The Facts

√ Field-measured FFS = 70 km/h,
√ Access control is good,
√ Analysis period = 1.00 h,
√ Segment lengths and travel times are collected according to the method described in Appendix A,
√ Multilane divided facility, and
√ About 3 signals per kilometer.

Outline of Solution Since segment lengths and travel times are collected in the field, urban street speeds and LOS can be determined directly. The following describes the steps in the computations.

Steps

1. Find urban street class (use Exhibits 10-3 and 10-4, and field-measured FFS).	Suburban street—Urban street Class II
2. Find S_A (use Equation 15-6). ST and L are given on the worksheet.	$S_A = \frac{3,600(L)}{ST}$ Segment 1 S_A = $S_A = \frac{3,600(0.30)}{28.3}$ = 38.2 km/h Segment 2 S_A = 46.9 km/h Segment 3 S_A = 41.3 km/h Segment 4 S_A = 36.7 km/h Segment 5 S_A = 29.0 km/h Segment 6 S_A = 35.5 km/h Segment 7 S_A = 40.9 km/h Segment 8 S_A = 38.4 km/h
3. Find S_A for the entire urban street (use Equation 15-6).	$\sum ST$ = 252.3 s $\sum L$ = 2.6 km $S_A = \frac{3,600\sum L}{\sum ST} = \frac{3,600(2.6)}{252.3} =$ 37.1 km/h
4. Determine urban street LOS and segment LOS (use Exhibit 15-2).	

Results

- Segment 1, LOS C;
- Segment 2, LOS B;
- Segment 3, LOS C;
- Segment 4, LOS C;
- Segment 5, LOS D;
- Segment 6, LOS C;
- Segment 7, LOS C;
- Segment 8, LOS C; and
- Urban street, LOS C.

Example Problem 3

URBAN STREET WORKSHEET

General Information		**Site Information**	
Analyst	*JMYE*	Urban Street	
Agency or Company	*CEI*	Direction of Travel	*EB*
Date Performed	*5/11/99*	Jurisdiction	
Analysis Time Period	*PM Peak*	Analysis Year	*1999*

☒ Operational (LOS) ☐ Design (v_p) ☐ Planning (LOS) ☐ Planning (v_p) Analysis Period, T = *1.00* h

Input Parameters	Segments							
	1	2	3	4	5	6	7	8
Cycle length, C (s)								
Effective green-to-cycle-length ratio, g/C								
v/c ratio for lane group, X								
Capacity of lane group, c (veh/h)								
Arrival type, AT								
Length of segment, L (km)	*0.30*	*0.25*	*0.25*	*0.30*	*0.40*	*0.40*	*0.40*	*0.30*
Initial queue, Q_b (veh)	-	-	-	-	-	-	-	-
Urban street class, SC (Exhibit 10-3)	*II*	*II*	*II*	*II*	*II*	*II*	*II*	*II*
Free-flow speed, FFS (km/h) (Exhibit 15-2)	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*
Running time, T_R (s) (Exhibit 15-3)								
Delay Computation								
Uniform delay, d_1 (s) $d_1 = \frac{0.5C[(1 - g/C)^2]}{1 - [(g/C)\min(X, 1.0)]}$								
Signal control adjustment factor, k (Exhibit 15-6)								
Upstream filtering/metering adjustment factor, I (Exhibit 15-7)								
Incremental delay, d_2 (s) $d_2 = 900T\left[(X - 1) + \sqrt{(X - 1)^2 + \frac{8kIX}{cT}}\right]$								
Initial queue delay, d_3 (s) (Ch. 16 Appendix F)								
Progression adjustment factor, PF (Exhibit 15-5)								
Control delay, d (s) $d = (d_1 * PF) + d_2 + d_3$								
Segment LOS Determination								
Segment travel time, ST (s) $ST = T_R + d$ + Other delay	*28.3*	*19.2*	*21.8*	*29.4*	*49.7*	*40.6*	*35.2*	*28.1*
Segment travel speed, S_A (km/h) $S_A = \frac{3600(L)}{ST}$	*38.2*	*46.9*	*41.3*	*36.7*	*29.0*	*35.5*	*40.9*	*38.4*
Segment LOS (Exhibit 15-2)	*C*	*B*	*C*	*C*	*D*	*C*	*C*	*C*

Urban Street LOS Determination

Total travel time = $\sum ST$	*252.3*	s
Total length = $\sum L$	*2.6*	km
Total travel speed, $S_A = \frac{3600 * \text{Total length}}{\text{Total travel time}}$	*37.1*	km/h
Total urban street LOS (Exhibit 15-2)	*C*	

EXAMPLE PROBLEM 4

The Urban Street A 3.2-km divided four-lane urban street with four signalized intersections at 0.8-km spacing. All intersections have left-turn bays.

The Question What are the LOS, control delay, and peak 15-min flow rate for through volume?

The Facts

- √ FFS = 70 km/h,
- √ AADT = 30,000,
- √ K = 0.091, D = 0.568,
- √ PHF = 0.925,
- √ s = 1,850 pc/h/ln,
- √ P_{LT} = 0.12,
- √ Urban street Class II,
- √ Arrival Type 3,
- √ Actuated signal,
- √ Cycle length = 120 s,
- √ Average g/C = 0.42, and
- √ Analysis period = 0.25 h.

Outline of Solution All input parameters are known for a planning application. The through-volume peak 15-min flow rate, urban street speed, and LOS are computed.

Steps

1. Find V.	V = AADT * K * D V = 30,000 * 0.091 * 0.568 = 1,551 veh/h
2. Find 15-min through flow rate.	$v_p = \frac{V(1 - P_{LT})}{PHF}$ $v_p = \frac{1551\,(1 - 0.12)}{0.925} = 1{,}476$ veh/h
3. Find c and X.	c = s * N * (g/C) c = 1850 * 2 * 0.42 = 1,554 pc/h $X = \frac{v}{c} = \frac{1476}{1554} = 0.950$
4. Find PF, k, and I (use Exhibits 15-5, 15-6, and 15-7).	PF = 1.0, k = 0.5. Assume I = 1.0 (for Intersection 1) and I = 0.207 is calculated for others
5. Find d_1 (use Equation 15-2).	$d_1 = \frac{0.5(120)(1 - 0.42)^2}{1 - (0.42)(0.950)} = 33.6$ s
6. Find d_2 (use Equation 15-3).	$d_2 = 900(0.25)\left[(0.950-1)+\sqrt{(0.950-1)^2+\frac{8*0.5*1.0*0.950}{1554(0.25)}}\right]$ d_2 = 13.7 s
7. Find d (use Equation 15-1).	d = (33.6 * 1.0) + 13.7 = 47.3 s
8. Find running time for a segment length of 800 m (use Exhibit 15-3).	Running time per km = 56 s/km T_R = 56 * 0.8 = 44.8 s
9. Find S_A for a segment (use Equation 15-6).	$S_A = \frac{3{,}600(0.8)}{(44.8+47.3)} =$ 31.3 km/h, LOS D
10. Find S_A for the entire urban street (use Equation 15-6).	$S_A =$ 34.0 km/h
11. Determine LOS (use Exhibit 15-2).	LOS C

Results
- Peak 15-min flow rate = 1,476 veh/h,
- Intersection control delay = 47.3 + 37.5 * 3 = 159.8 s, and
- LOS C.

Example Problem 4

URBAN STREET WORKSHEET

General Information		**Site Information**	
Analyst	*JMYE*	Urban Street	
Agency or Company	*CEI*	Direction of Travel	*Peak direction*
Date Performed	*5/20/99*	Jurisdiction	
Analysis Time Period	*Peak*	Analysis Year	*1999*

❑ Operational (LOS) ❑ Design (v_p) ☒ Planning (LOS) ❑ Planning (v_p) Analysis Period, T = *0.25* h

Input Parameters

	Segments 1	2	3	4	5	6	7	8
Cycle length, C (s)	120	120	120	120				
Effective green-to-cycle-length ratio, g/C	0.42	0.42	0.42	0.42				
v/c ratio for lane group, X	0.950	0.950	0.950	0.950				
Capacity of lane group, c (veh/h)	1,554	1,554	1,554	1,554				
Arrival type, AT	3	3	3	3				
Length of segment, L (km)	0.8	0.8	0.8	0.8				
Initial queue, Q_b (veh)	-	-	-	-				
Urban street class, SC (Exhibit 10-3)	II	II	II	II				
Free-flow speed, FFS (km/h) (Exhibit 15-2)	70	70	70	70				
Running time, T_R (s) (Exhibit 15-3)	44.8	44.8	44.8	44.8				
Delay Computation								
Uniform delay, d_1 (s) $d_1 = \frac{0.5C[(1 - g/C)^2]}{1 - [(g/C)\min(X, 1.0)]}$	33.6	33.6	33.6	33.6				
Signal control adjustment factor, k (Exhibit 15-6)	0.5	0.5	0.5	0.5				
Upstream filtering/metering adjustment factor, I (Exhibit 15-7)	1.0	0.207	0.207	0.207				
Incremental delay, d_2 (s) $d_2 = 900T\left[(X - 1) + \sqrt{(X - 1)^2 + \frac{8kIX}{cT}}\right]$	13.7	3.9	3.9	3.9				
Initial queue delay, d_3 (s) (Ch. 16 Appendix F)	0.0	0.0	0.0	0.0				
Progression adjustment factor, PF (Exhibit 15-5)	1.0	1.0	1.0	1.0				
Control delay, d (s) $d = (d_1 * PF) + d_2 + d_3$	47.3	37.5	37.5	37.5				
Segment LOS Determination								
Segment travel time, ST (s) $ST = T_R + d + \text{Other delay}$	92.1	82.3	82.3	82.3				
Segment travel speed, S_A (km/h) $S_A = \frac{3600(L)}{ST}$	31.3	35.0	35.0	35.0				
Segment LOS (Exhibit 15-2)	D	C	C	C				

Urban Street LOS Determination

Total travel time = $\sum ST$	339.0	s
Total length = $\sum L$	3.2	km
Total travel speed, $S_A = \frac{3600 * \text{Total length}}{\text{Total travel time}}$	34.0	km/h
Total urban street LOS (Exhibit 15-2)	C	

EXAMPLE PROBLEM 5

The Urban Street A new 3.6-km six-lane facility with six signalized intersections at 0.6-km spacing.

The Question What is the lowest acceptable travel speed, hourly directional volume, and annual average daily traffic to achieve LOS D?

The Facts

- √ FFS = 65 km/h,
- √ K = 0.095, D = 0.55,
- √ PHF = 0.95,
- √ s = 1,750 pc/h/ln,
- √ P_{LT} = 0.12,
- √ Analysis period = 0.25 h,
- √ Urban street Class II,
- √ Arrival Type 5,
- √ Semiactuated signals,
- √ Cycle length = 120 s, and
- √ g/C = 0.42.

Outline of Solution All input parameters are known. Find the lowest acceptable travel speed to achieve LOS D, and backsolve for flow rate, volume, and AADT.

Steps

1. Find the lowest acceptable travel speed for urban street Class II and LOS D (use Exhibit 15-2).	S_A = 26.1 km/h
2. Find travel time for segment length of 600 m (use Exhibit 15-3).	Running time per km = 61 s/km T_R = 61 * 0.6 = 36.6 s Urban street travel time = 6 * 36.6 = 219.6 s
3. Find d for the total urban street (use Equation 15-6).	$d = \frac{3,600}{S_A} - T_R$ $d = \frac{3,600(3.6)}{26.1} - 219.6 =$ 277.0 s/veh
4. Find PF, k, and I (use Exhibits 15-5, 15-6, and 15-7).	PF = 0.511, k = 0.5 Assume I = 1.0 (Intersection 1) I = 0.090 is calculated for Intersections 2 through 6
5. Find c (use Equation 15-7).	c = N * s * (g/C) c = 3 * 1,750 * 0.42 = 2,205 veh/h
6. Find X (use Equations 15-1, 15-2, and 15-3).	$d = \sum_{1}^{6} d_i$ = 277 s/veh $d = 6d_1 * PF + d_2$ (Int. 1) + $5d_2$ (Int. 2–6) $d = 6 * 0.511 * d_1 + d_2$ (Int. 1) + $5d_2$ (Int. 2–6) $d = 3.066d_1 + d_2$ (Int. 1) + $5d_2$ (Int. 2–6) $d_1 = \frac{0.5(120)(1 - 0.42)^2}{1 - 0.42X}$ $d_1 = \frac{20.184}{1 - 0.42X}$

6. (continued)	d_2 for Intersection 1 $d_2 = 900(0.25)\left[(X-1)+\sqrt{(X-1)^2+\frac{8*0.5*10*X}{2,205(0.25)}}\right]$ $d_2 = 225\left[(X-1)+\sqrt{(X-1)^2+\frac{4X}{551.25}}\right]$ d_2 for Intersections 2–6 $d_2 = 225\left[(X-1)+\sqrt{(X-1)^2+\frac{0.36X}{551.25}}\right]$ by trial and error, X = 1.05
7. Find V_h and AADT	$V_h = \frac{X*c*PHF}{(1-P_{LT})} = \frac{1.05*2205*0.95}{1-0.12} = 2{,}499$ veh/h $AADT = \frac{V_h}{D*K} = \frac{2499}{0.55*0.095} = 47{,}828$ veh/day

Results

- V_h = 2,499 veh/h,
- AADT = 47,828 veh/day, and
- S_A = 26.1 km/h.

APPENDIX A. PLANNING APPLICATION COMPUTATIONS

The calculation process for determining urban street LOS is shown in Exhibit A15-1 and consists of the following steps.

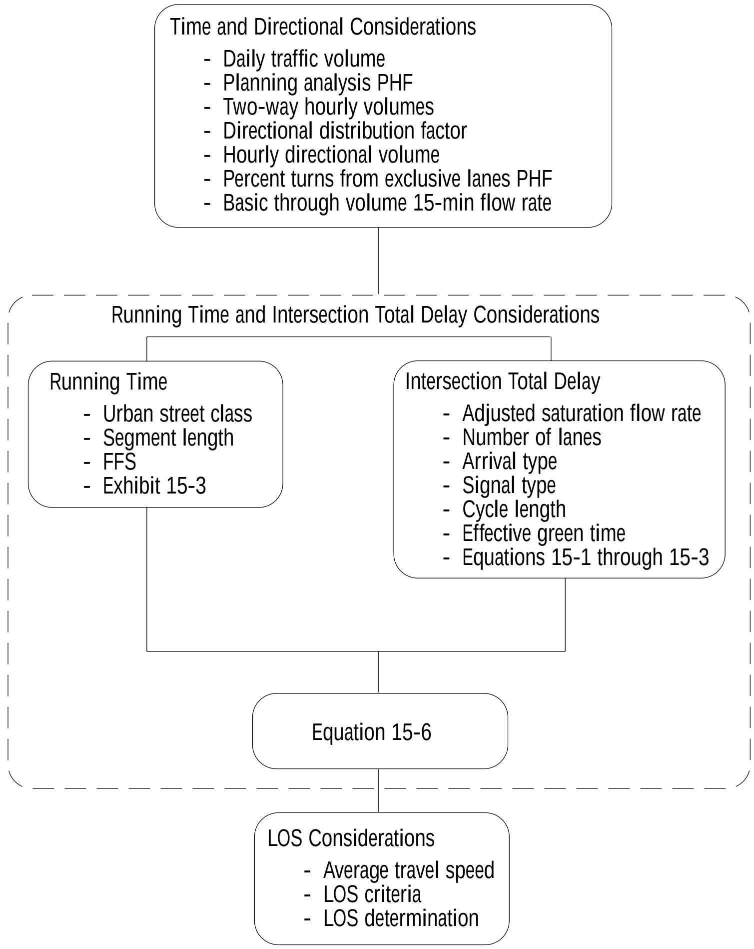
1. Convert daily volumes to the planning analysis hour by using an appropriate K-factor.
2. Multiply K by the directional distribution factor D to obtain hourly directional volumes.
3. Adjust the hourly directional volumes based on PHF and turns from exclusive lanes to yield estimated through volumes for 15-min service flow rates.
4. Calculate the running time on the basis of urban street classification, intersection spacing, and FFS.
5. Using Equation 15-1, calculate the intersection control delay on the basis of adjusted saturation flow rates, number of lanes N, arrival type, signal type, cycle length C, and g/C for each intersection.
6. Using running time and intersection control delay, calculate the average travel speed.
7. Obtain urban street LOS on the basis of the average travel speed.

Example Problem 4 in this chapter illustrates the computational steps for a planning analysis.

Frequently in a planning analysis, however, the LOS may be given and the desired outcome is a volume—hourly directional, hourly nondirectional, or daily. For these applications, the calculation is reversed, as follows.

1. Select the LOS and the corresponding average travel speed (range or minimum) based on urban street type and FFS, selected from Exhibit 15-2.
2. Compute the total section running time for the urban street type, number of intersections, FFS, and section length.
3. Using Equation 15-6 and steps 1 and 2, calculate the control delay d at all intersections.

EXHIBIT A15-1. URBAN STREET LOS CALCULATIONS



4. Compute v by inserting the values for average control delay, the adjusted saturated flow rate for the number of lanes, the arrival type, C, and weighted g/C into Equations 15-1 through 15-3.

5. Use the percentage of turns from exclusive lanes, basic through 15-min volumes, and the PHF to determine the hourly directional volume for the design hour.

6. Use the hourly directional volume and the directional distribution factor to calculate the two-way hourly directional volume for the design hour.

7. Use the two-way hourly directional volume and the applicable K-factor to determine AADT.

The results of a planning analysis can range from a rough estimate of LOS to a precise operational analysis, depending primarily on the extent to which default values are used as input. For example, using statewide defaults for appropriate traffic, roadway, and signal characteristics will produce rough LOS estimates. Using area- or roadway-specific data but treating all signal characteristics the same (e.g., using a weighted g/C approach) should provide more accurate LOS estimates. However, using specific traffic, roadway, and signal data for each road segment and traffic signal would provide an even more accurate estimate. The next level of precision is a detailed treatment of turning movements and signal timing, which approaches an operational analysis but uses projected instead of actual traffic volumes.

APPENDIX B. TRAVEL TIME STUDIES FOR DETERMINING LOS

The following steps apply the test-car method for determining travel time and LOS for urban streets.

1. Identify and inventory the geometrics and the access control of each street segment, the segment lengths, the signal timing, and the 15-min flow rates for selected times of the day—such as the peak a.m. period, the peak p.m. period, and a representative off-peak period—by direction of flow.

2. Determine the appropriate FFS for the street section. This can be determined by making runs with a test car equipped with a calibrated speedometer during periods of low volume. An observer should read the speedometer at midblock locations when the vehicle is not impeded by other vehicles and record speed readings for each segment. These observations can be supplemented by spot speed studies at typical midblock locations during low-volume conditions. Other data, such as design type, access points, roadside development, and speed limit, also may be considered.

3. Use Exhibits 10-3 and 10-4 along with the physical information and FFS to determine the urban street class.

4. Make test-car travel time runs over the street section during the selected times.

a. Use the appropriate equipment to obtain the information identified in Exhibit B15-1. The equipment may be computerized or simply a pair of stopwatches.

b. Travel times between the centers of signalized intersections should be recorded, along with the location, cause, and duration of each stop.

c. Test-car runs should begin at different time points in the signal cycle to avoid all trips starting first in the platoon.

d. Some midblock speedometer readings also should be recorded to check on unimpeded travel speeds and how they relate to FFS.

e. Data should be summarized for each segment and each time period, the average travel time, the average stopped time for the signal, and other stops and events (four-way stops, parking disruptions, etc.).

f. The number of test-car runs will depend on the variance in the data. Six to 12 runs may be adequate for each traffic-volume condition.

g. If available, an instrumented test car should be used to reduce labor requirements and to facilitate recording and analysis. Summaries of test-car runs with all data recorded and analyzed by the computer are now common.

5. The average travel speed, based on travel times and segment lengths, should be determined for each segment for each time period. Average travel speed for the entire urban street section should also be determined.

6. From Exhibit 15-2, obtain a LOS value for each urban street segment and for the overall urban street for each time period and direction of flow. This is done by comparing the average travel speed from step 5 with the speed values for the appropriate street class in Exhibit 15-2.

7. The test-car data can be modified to evaluate different signal timing plans. As shown in Exhibit 15-5, adjustment factors can be applied to delays to evaluate how the changes would affect average travel speeds and LOS.

EXHIBIT B15-1. TRAVEL-TIME FIELD WORKSHEET

TRAVEL-TIME FIELD WORKSHEET

General Information		**Site Information**	
Analyst	______________	Urban Street	______________
Agency or Company	______________	Direction of Travel	______________
Date Performed	______________	Jurisdiction	______________
Analysis Time Period	______________	Analysis Year	______________

Field Data

		Run No. ________ Time ________			Run No. ________ Time ________			Run No. ________ Time ________		
Signal Location	Distance (km)	Cumulative Travel Time (s)		Delay Time (s)	Cumulative Travel Time (s)		Delay Time (s)	Cumulative Travel Time (s)		Delay Time (s)

APPENDIX C. WORKSHEETS

URBAN STREET WORKSHEET

TRAVEL-TIME FIELD WORKSHEET

URBAN STREET WORKSHEET

General Information		Site Information	
Analyst	____________	Urban Street	____________
Agency or Company	____________	Direction of Travel	____________
Date Performed	____________	Jurisdiction	____________
Analysis Time Period	____________	Analysis Year	____________

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p) Analysis Period, T =________ h

Input Parameters

	Segments							
	1	2	3	4	5	6	7	8
Cycle length, C (s)								
Effective green-to-cycle-length ratio, g/C								
v/c ratio for lane group, X								
Capacity of lane group, c (veh/h)								
Arrival type, AT								
Length of segment, L (km)								
Initial queue, Q_b (veh)								
Urban street class, SC (Exhibit 10-3)								
Free-flow speed, FFS (km/h) (Exhibit 15-2)								
Running time, T_R (s) (Exhibit 15-3)								

Delay Computation

	1	2	3	4	5	6	7	8
Uniform delay, d_1 (s) $d_1 = \frac{0.5C[(1 - g/C)^2]}{1 - [(g/C)\min(X, 1.0)]}$								
Signal control adjustment factor, k (Exhibit 15-6)								
Upstream filtering/metering adjustment factor, I (Exhibit 15-7)								
Incremental delay, d_2 (s) $d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right]$								
Initial queue delay, d_3 (s) (Ch. 16 Appendix F)								
Progression adjustment factor, PF (Exhibit 15-5)								
Control delay, d (s) $d = (d_1 * PF) + d_2 + d_3$								

Segment LOS Determination

	1	2	3	4	5	6	7	8
Segment travel time, ST (s) $ST = T_R + d + \text{Other delay}$								
Segment travel speed, S_A (km/h) $S_A = \frac{3600(L)}{ST}$								
Segment LOS (Exhibit 15-2)								

Urban Street LOS Determination

Total travel time = $\sum ST$ ________________s

Total length = $\sum L$ ________________km

Total travel speed, $S_A = \frac{3600 * \text{Total length}}{\text{Total travel time}}$ ________________km/h

Total urban street LOS (Exhibit 15-2) ________________

TRAVEL-TIME FIELD WORKSHEET

General Information

Analyst ______________________________

Agency or Company ______________________________

Date Performed ______________________________

Analysis Time Period ______________________________

Site Information

Urban Street ______________________________

Direction of Travel ______________________________

Jurisdiction ______________________________

Analysis Year ______________________________

Field Data

Signal Location	Distance (km)	Run No. ___________ Time _____________ Cumulative Travel Time (s)		Delay Time (s)	Run No. ___________ Time _____________ Cumulative Travel Time (s)		Delay Time (s)	Run No. ___________ Time _____________ Cumulative Travel Time (s)		Delay Time (s)