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CHAPTER 17
URBAN STREET SEGMENTS

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

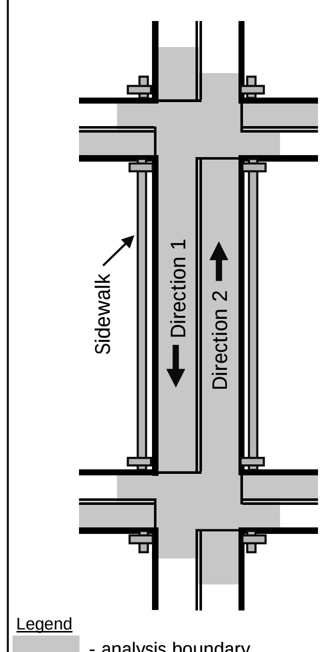
Chapter 17, Urban Street Segments, describes a methodology for evaluating the capacity and quality of service provided to road users traveling along an urban street segment. However, the methodology is much more than just a tool for evaluating capacity and quality of service. The methodology includes an array of performance measures that more fully describes segment operation for multiple travel modes. These measures serve as clues in identifying the source of problems and provide insight into the development of effective improvement strategies. The analyst is encouraged to consider the full range of measures when using this methodology.

OVERVIEW OF THE METHODOLOGY

This chapter's methodology is applicable to an urban or suburban street segment. The segment can be part of an arterial or collector street with one-way or two-way vehicular traffic flow. The intersections on the segment can be signalized or unsignalized.

Analysis Boundaries

The segment analysis boundary is defined by the roadway right-of-way and the operational influence area of each boundary intersection. The influence area of a boundary intersection extends backward from the intersection on each intersection leg. The size of this area is leg-specific and includes the most distant extent of any intersection-related queue expected to occur during the study period. For these reasons, the analysis boundaries should be established for each intersection on the basis of the conditions present during the analysis period. Practically speaking, the influence area should extend at least 250 ft back from the stop line on each intersection leg.



Analysis Level

Analysis level describes the level of detail used in applying the methodology. Three levels are recognized:

- Operational,
- Design, and
- Planning and preliminary engineering.

The operational analysis is the most detailed application and requires the most information about the traffic, geometric, and signalization conditions. The design analysis also requires detailed information about the traffic conditions and the desired level of service (LOS) as well as information about either the geometric or signalization conditions. The design analysis then seeks to determine reasonable values for the conditions not provided. The planning and preliminary engineering analysis requires only the most fundamental types of information from the analyst. Default values are then used as substitutes for other input data. The subject of analysis level is discussed in more detail in the Applications section of this chapter.

Study Period and Analysis Period

The study period is the time interval represented by the performance evaluation. It consists of one or more consecutive analysis periods. An analysis period is the time interval evaluated by a single application of the methodology.

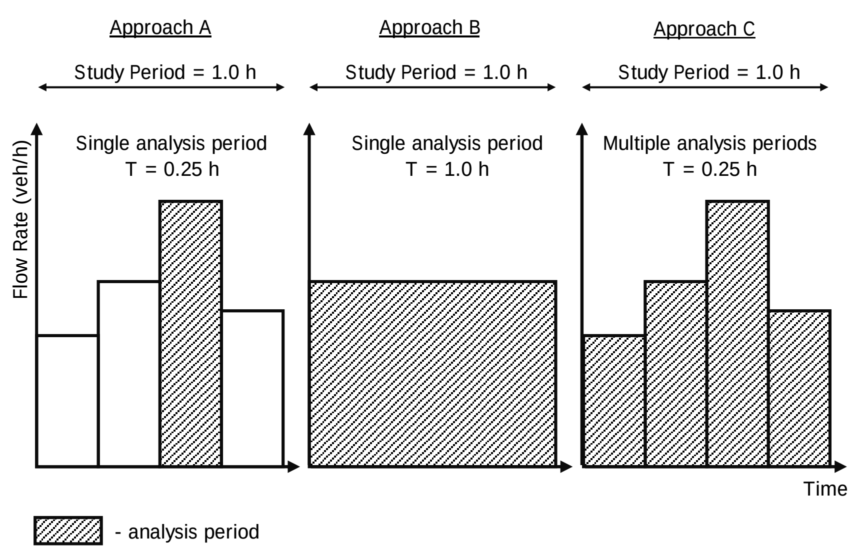
The methodology is based on the assumption that traffic conditions are steady during the analysis period (i.e., systematic change over time is negligible). For this reason, the duration of the analysis period is in the range of 0.25 to 1 h. The longer durations in this range are sometimes used for planning analyses. In general, the analyst should use caution with analysis periods that exceed 1 h because traffic conditions are not typically steady for long time periods and because the adverse impact of short peaks in traffic demand may not be detected in the evaluation.

If an analysis period of interest has a demand volume that exceeds capacity, then the study period should include an initial analysis period with no initial queue and a final analysis period with no residual queue. This approach provides a more accurate estimate of the delay associated with the congestion.

If evaluation of multiple analysis periods is determined to be important, then the performance estimates for each period should be separately reported. In this situation, reporting an average performance for the study period is not encouraged because it may obscure extreme values and suggest acceptable operation when in reality some analysis periods have unacceptable operation.

Exhibit 17-1 demonstrates three alternative approaches an analyst might use for a given evaluation. Note that other alternatives exist and that the study period can exceed 1 h. Approach A is the one that has traditionally been used and, unless otherwise justified, is the one that is recommended for use.

Exhibit 17-1
Three Alternative Study Approaches



Approach A is based on the evaluation of the peak 15-min period during the study period. The analysis period *T* is 0.25 h. The equivalent hourly flow rate used for the analysis is based on either a peak 15-min traffic count multiplied by four or a 1-h demand volume divided by the peak hour factor. The former option is preferred whenever traffic counts are available. The peak hour factor equals the hourly count of vehicles divided by four times the peak 15-min count for a common hour interval. It is provided by the analyst or operating agency.

Approach B is based on the evaluation of one 1-h analysis period that is coincident with the study period. The analysis period T is 1.0 h. The flow rate used is equivalent to the 1-h demand volume (i.e., the peak hour factor is not used). This approach implicitly assumes that the arrival rate of vehicles is constant throughout the period of study. Therefore, the effects of peaking within the hour may not be identified, and the analyst risks underestimating the delay actually incurred.

Approach C uses a 1-h study period and divides it into four 0.25-h analysis periods. This approach accounts for systematic flow rate variation among analysis periods. It also accounts for queues that carry over to the next analysis period and produces a more accurate representation of delay.

Performance Measures

A street segment's performance is described by the use of one or more quantitative measures that characterize some aspect of the service provided to a specific road-user group. Performance measures cited in this chapter include automobile travel speed, automobile stop rate, automobile traveler perception score, pedestrian travel speed, pedestrian space, pedestrian perception score, bicycle travel speed, bicycle perception score, transit vehicle travel speed, transit wait–ride score, and transit passenger perception score.

LOS is also considered a performance measure. It is computed for the automobile, pedestrian, bicycle, and transit travel modes. It is useful for describing segment performance to elected officials, policy makers, administrators, or the public. LOS is based on one or more of the performance measures listed in the previous paragraph.

Travel Modes

This chapter describes a separate methodology for evaluating urban street performance from the perspective of motorists, pedestrians, bicyclists, or transit passengers. These methodologies are referred to as the automobile methodology, pedestrian methodology, bicycle methodology, and transit methodology.

Each methodology consists of a set of procedures for computing the quality of service provided to one mode. Collectively, they can be used to evaluate the urban street segment operation from a multimodal perspective.

Each methodology is focused on the evaluation of a street segment (with consideration given to the intersections that bound it). The aggregation of segment performance measures to obtain an estimate of facility performance is described in Chapter 16, Urban Street Facilities. Methodologies for evaluating the intersections on the urban street are described in Chapters 18 to 22.

The four methodologies described in this chapter are based largely on the products of two National Cooperative Highway Research Program projects (*1*, *2*). Contributions to the methodology from other research are referenced in the relevant sections.

The transit methodology described in this chapter is applicable to the evaluation of passenger service provided by local public transit vehicles operating in mixed traffic or exclusive lanes and stopping along the street. Nonlocal transit vehicle speed and delay are evaluated by using the automobile methodology.

The phrase *automobile mode*, as used in this chapter, refers to travel by all motorized vehicles that can legally operate on the street, with the exception of local transit vehicles that stop to pick up passengers along the street. Unless explicitly stated otherwise, the word *vehicles* refers to motorized vehicles and includes a mixed stream of automobiles, motorcycles, trucks, and buses.

Lane Groups and Movement Groups

Lane group and *movement group* are phrases used to define combinations of intersection movements for the purpose of evaluating signalized intersection operation. These two terms are used extensively in Chapter 18, Signalized Intersections. They are also used in this chapter when the boundary intersection is signalized.

The automobile methodology in Chapter 18 is designed to evaluate the performance of designated lanes, groups of lanes, an intersection approach, and the entire intersection. A lane or group of lanes designated for separate analysis is referred to as a *lane group*. In general, a separate lane group is established for (*a*) each lane (or combination of adjacent lanes) that exclusively serves one movement and (*b*) each lane shared by two or more movements.

The concept of *movement groups* is also established to facilitate data entry. A separate movement group is established for (*a*) each turn movement with one or more exclusive turn lanes and (*b*) the through movement (inclusive of any turn movements that share a lane).

URBAN STREET SEGMENT DEFINED

For the purpose of analysis, the roadway is separated into individual elements that are physically adjacent and operate as a single entity in serving travelers. Two elements are commonly found on an urban street system: points and links. A *point* represents the boundary between links and is represented by an intersection or ramp terminal. A *link* represents a length of roadway between two points. A link and its boundary points are referred to as a *segment*.

Previous editions of this manual have allowed the evaluation of one direction of travel along a segment (even when it served two-way traffic). This approach is retained in this chapter for the analysis of bicycle and transit performance. For the analysis of pedestrian performance, this approach translates into the evaluation of sidewalk and street conditions on one side of the segment.

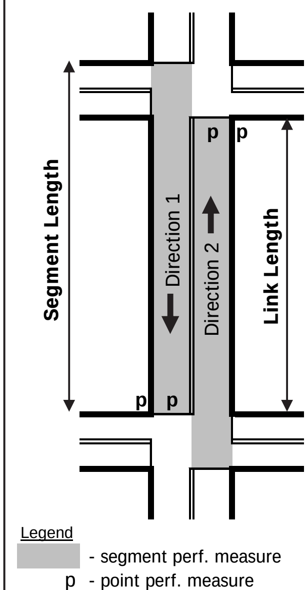
For the automobile methodology, a segment evaluation considers both directions of travel (when the street serves two-way traffic).

For the analysis of automobile performance, an analysis of only one travel direction (when the street serves two-way traffic) does not adequately recognize the interactions between vehicles at the boundary intersections and their influence on segment operation. For example, the automobile methodology in this edition of the *Highway Capacity Manual* (HCM) explicitly models the platoon formed by the signal at one end of the segment and its influence on the operation of the signal at the other end of the segment. For these reasons, it is important to evaluate both travel directions on a two-way segment.

Points and Segments

A segment performance measure combines link performance and point performance.

The link and its boundary points must be evaluated together to provide an accurate indication of overall segment performance. For a given direction of travel along the segment, link and downstream point performance measures are combined to determine overall segment performance.



If the subject segment is within a coordinated signal system, then the following rules apply when the segment boundaries are identified:

- A signalized intersection (or ramp terminal) is always used to define a segment boundary.
- Only intersections (or ramp terminals) at which the segment through movement is uncontrolled (e.g., a two-way STOP-controlled intersection) can exist along the segment between the boundaries.

If the subject segment is not within a coordinated signal system, then the following rules apply when the segment boundaries are identified:

- An intersection (or ramp terminal) having a type of control that can impose on the segment through movement a legal requirement to stop or yield must always be used to define a segment boundary.
- An intersection (or ramp terminal) at which the segment through movement is uncontrolled (e.g., a two-way STOP-controlled intersection) may be used to define a segment boundary, but it is typically not done.

A midsegment traffic control signal provided for the exclusive use of pedestrians should not be used to define a segment boundary. This restriction reflects the fact that the methodologies described here were derived for, and calibrated with data from, street segments bounded by an intersection.

An access point intersection is an unsignalized intersection with one or two access point approaches to the segment. The approach can be a driveway or a public street. The through movements on the segment are uncontrolled at an access point intersection.

Segment Length Considerations

When a segment has a "short" length, then the interaction between traffic movements and traffic control devices at the two boundary intersections is sufficiently complex that a separate analysis of each element will not provide an accurate indication of urban street performance. This complication can occur regardless of the type of control present at the two boundary intersections; however, it is particularly complicated when the two intersections are signalized. The automobile methodology described in this chapter is not appropriate for the analysis of short segments. In contrast, the methodology described in Chapter 22, Interchange Ramp Terminals, is appropriate for the analysis of short segments at signalized interchanges.

It is difficult to define specific conditions under which a segment is short. However, two general rules apply in making this determination. First, a segment is considered to be short if the queue frequently extends back from one intersection into the other intersection (i.e., spills back) during the analysis period. Second, a segment is considered to be short if the through signal phase duration at the downstream intersection is longer than that needed to serve all the vehicles that store on the segment plus any vehicles that can enter it from the upstream signalized intersection while the downstream phase is green. This situation results in "demand starvation." It leads to the inefficient use of the downstream through phase and the retention of unserved vehicles on the approaches to the upstream intersection. In general, segments that are bounded by signalized intersections and are shorter than 400 ft may experience one or both of these conditions.

Platoons formed at a signalized intersection are typically dispersed by the time they reach a point about 0.6 mi downstream of the signal. This distance can vary depending on the amount of access point activity along the street and the speed of the traffic stream. Regardless, the influence of platoons on urban street operation is very likely to be negligible when segment length exceeds 2 mi. Therefore, if a segment exceeds 2 mi in length and its boundary points are signalized, then the analyst should evaluate the segment as an uninterrupted-flow highway segment with isolated intersections.

LOS CRITERIA

This subsection describes the LOS criteria for the automobile, pedestrian, bicycle, and transit modes. The criteria for the automobile mode are different from the criteria used for the nonautomobile modes. Specifically, the automobile mode criteria are based on performance measures that are field-measurable and perceivable by travelers. The criteria for the pedestrian and bicycle modes are based on scores reported by travelers indicating their perception of service quality. The criteria for the transit mode are based on measured changes in transit patronage due to changes in service quality.

Automobile Mode

All uses of the word "volume" or the phrase "volume-to-capacity ratio" in this chapter refer to demand volume or demand-volume-to-capacity ratio.

Two performance measures are used to characterize vehicular LOS for a given direction of travel along an urban street segment. One measure is travel speed for through vehicles. This speed reflects the factors that influence running time along the link and the delay incurred by through vehicles at the boundary intersection. The second measure is the volume-to-capacity ratio for the through movement at the downstream boundary intersection. These performance measures indicate the degree of mobility provided by the segment. The following paragraphs characterize each service level.

LOS A describes primarily free-flow operation. Vehicles are completely unimpeded in their ability to maneuver within the traffic stream. Control delay at the boundary intersection is minimal. The travel speed exceeds 85% of the base free-flow speed, and the volume-to-capacity ratio is no greater than 1.0.

LOS B describes reasonably unimpeded operation. The ability to maneuver within the traffic stream is only slightly restricted, and control delay at the boundary intersection is not significant. The travel speed is between 67% and 85% of the base free-flow speed, and the volume-to-capacity ratio is no greater than 1.0.

LOS C describes stable operation. The ability to maneuver and change lanes at midsegment locations may be more restricted than at LOS B. Longer queues at the boundary intersection may contribute to lower travel speeds. The travel speed is between 50% and 67% of the base free-flow speed, and the volume-to-capacity ratio is no greater than 1.0.

LOS D indicates a less stable condition in which small increases in flow may cause substantial increases in delay and decreases in travel speed. This operation may be due to adverse signal progression, high volume, or inappropriate signal timing at the boundary intersection. The travel speed is between 40% and 50% of the base free-flow speed, and the volume-to-capacity ratio is no greater than 1.0.

LOS E is characterized by unstable operation and significant delay. Such operations may be due to some combination of adverse progression, high volume, and inappropriate signal timing at the boundary intersection. The travel speed is between 30% and 40% of the base free-flow speed, and the volume-to-capacity ratio is no greater than 1.0.

LOS F is characterized by flow at extremely low speed. Congestion is likely occurring at the boundary intersection, as indicated by high delay and extensive queuing. The travel speed is 30% or less of the base free-flow speed, or the volume-to-capacity ratio is greater than 1.0.

Exhibit 17-2 lists the LOS thresholds established for the automobile mode on urban streets.

Exhibit 17-2
LOS Criteria: Automobile Mode

Travel Speed as a Percentage of Base Free-Flow Speed (%)	LOS by Volume-to-Capacity Ratio[a]	
	≤1.0	> 1.0
>85	A	F
>67–85	B	F
>50–67	C	F
>40–50	D	F
>30–40	E	F
≤30	F	F

Note: [a] Volume-to-capacity ratio of through movement at downstream boundary intersection.

Nonautomobile Modes

Historically, this manual has used a single performance measure as the basis for defining LOS. However, research documented in Chapter 5, Quality and Level-of-Service Concepts, indicates that travelers consider a wide variety of factors when they assess the quality of service provided to them. Some of these factors can be described as performance measures (e.g., speed), and others can be described as basic descriptors of the urban street character (e.g., sidewalk width). The methodology for evaluating each mode provides a procedure for mathematically combining these factors into a score. This score is then used to determine the LOS that is provided for a given direction of travel along a segment.

Exhibit 17-3 lists the scores associated with each LOS for the pedestrian travel mode. The LOS for this particular mode is determined by consideration of both the LOS score and the average pedestrian space on the sidewalk. The applicable LOS for an evaluation is determined from the table by finding the intersection of the row corresponding to the computed score value and the column corresponding to the computed space value.

Exhibit 17-3
LOS Criteria: Pedestrian Mode

Pedestrian LOS Score	LOS by Average Pedestrian Space (ft^2/p)					
	>60	>40–60	>24–40	>15–24	>8.0–15[a]	≤ 8.0[a]
≤2.00	A	B	C	D	E	F
>2.00–2.75	B	B	C	D	E	F
>2.75–3.50	C	C	C	D	E	F
>3.50–4.25	D	D	D	D	E	F
>4.25–5.00	E	E	E	E	E	F
>5.00	F	F	F	F	F	F

Note: [a] In cross-flow situations, the LOS E/F threshold is 13 ft^2/p.

The association between LOS score and LOS is based on traveler perception research. Travelers were asked to rate the quality of service associated with a specific trip along an urban street. The letter "A" was used to represent the "best" quality of service, and the letter "F" was used to represent the "worst" quality of service. "Best" and "worst" were left undefined, allowing the respondents to identify the best and worst conditions on the basis of their traveling experience and perception of service quality.

Exhibit 17-4 lists the range of scores that are associated with each LOS for the bicycle and transit modes. This exhibit is also applicable for determining pedestrian LOS when a sidewalk is not available.

Exhibit 17-4
LOS Criteria: Bicycle and Transit Modes

LOS	LOS Score
A	≤2.00
B	>2.00–2.75
C	>2.75–3.50
D	>3.50–4.25
E	>4.25–5.00
F	>5.00

REQUIRED INPUT DATA

This subsection describes the required input data for the automobile, pedestrian, bicycle, and transit methodologies. Default values for some of these data are described in Section 3, Applications.

Automobile Mode

This part describes the input data needed for the automobile methodology. The data are listed in Exhibit 17-5 and are identified as "input data elements." They must be separately specified for each direction of travel on the segment and for each boundary intersection.

The last column in Exhibit 17-5 indicates whether the input data are needed for a movement group at a boundary intersection, the overall intersection, or the segment. The input data needed to evaluate the boundary intersections are identified in the appropriate chapter (i.e., Chapters 18 to 22).

The data elements listed in Exhibit 17-5 do not include variables that are considered to represent calibration factors (e.g., acceleration rate). Default values are provided for these factors because they typically have a relatively narrow range of reasonable values or they have a small impact on the accuracy of the performance estimates. The recommended value for each calibration factor is identified at relevant points in the presentation of the methodology.

Exhibit 17-5
Input Data Requirements: Automobile Mode

Data Category	Location	Input Data Element	Basis
Traffic characteristics	Boundary intersection	Demand flow rate	Movement group
	Segment	Access point flow rate	Movement group
		Midsegment flow rate	Segment
Geometric design	Boundary intersection	Number of lanes	Movement group
		Upstream intersection width	Intersection
		Turn bay length	Segment approach
	Segment	Number of through lanes	Segment
		Number of lanes at access points	Segment approach
		Turn bay length at access points	Segment approach
		Segment length	Segment
		Restrictive median length	Segment
		Proportion of segment with curb	Segment
		Number of access point approaches	Segment
Other	Segment	Analysis period duration	Segment
		Speed limit	Segment
Performance measures	Boundary intersection	Through control delay	Through-movement group
		Through stopped vehicles	Through-movement group
		2nd- and 3rd-term back-of-queue size	Through-movement group
		Capacity	Movement group
	Segment	Midsegment delay	Segment
		Midsegment stops	Segment

Notes: Movement group = one value for each turn movement with exclusive lanes and one value for the through movement (inclusive of any turn movements in a shared lane).
Through-movement group = one value for the segment through movement at the downstream boundary intersection (inclusive of any turn movements in a shared lane).
Segment = one value or condition for each direction of travel on the segment.
Segment approach = one value or condition for each intersection approach on the subject segment.

Traffic Characteristics Data

This subpart describes the traffic characteristics data listed in Exhibit 17-5. These data describe the motorized vehicle traffic stream traveling along the street during the analysis period.

Demand Flow Rate

The demand flow rate for an intersection traffic movement is defined as the count of vehicles arriving at the intersection during the analysis period, divided by the analysis period duration. It is expressed as an hourly flow rate, but it may represent an analysis period shorter than 1 h. Guidance for estimating this rate is provided in the chapter that corresponds to the boundary intersection configuration (i.e., Chapters 18 to 22).

Access Point Flow Rate

The access point flow rate is defined as the count of vehicles arriving at an access point intersection during the analysis period, divided by the analysis period duration. It is expressed as an hourly flow rate, but it may represent an analysis period shorter than 1 h. It should represent a demand flow rate. It is needed for all intersecting movements at each active access point intersection.

An access point approach is considered to be *active* if it has sufficient volume to have some impact on segment operations during the analysis period. As a rule of thumb, an access point approach is considered active if it has an entering flow rate of 10 vehicles per hour (veh/h) or more during the analysis period.

If the segment has many access point intersections that are considered inactive but collectively have some impact on traffic flow, those intersections can be combined into one equivalent active access point intersection. Each nonpriority movement at the equivalent access point intersection has a flow rate that is equal to the sum of the corresponding nonpriority movement flow rates of each of the individual inactive access points.

There is one exception to the aforementioned definition of access point flow rate. Specifically, if a planning analysis is being conducted in which (*a*) the projected demand coincides with a 1-h period and (*b*) an analysis of the peak 15-min period is desired, then each movement's hourly demand can be divided by the intersection peak hour factor to predict the flow rate during the peak 15-min period. The peak hour factor used should be based on local traffic peaking trends.

Midsegment Flow Rate

The midsegment flow rate is defined as the count of vehicles traveling along the segment during the analysis period, divided by the analysis period duration. It is expressed as an hourly flow rate, but it may represent an analysis period shorter than 1 h. This volume is specified separately for each direction of travel along the segment.

If one or more access point intersections exist along the segment, then the midsegment flow rate should be measured at a location between these intersections (or between an access point and boundary intersection). The location chosen should be representative in terms of its having a flow rate similar to other locations along the segment. If the flow rate is believed to vary significantly along the segment, then it should be measured at several locations and an average used in the methodology.

There is one exception to the aforementioned definition of midsegment flow rate. Specifically, if a planning analysis is being conducted in which (*a*) the projected demand coincides with a 1-h period and (*b*) an analysis of the peak 15-min period is desired, then each movement's hourly demand can be divided by the peak hour factor to predict the flow rate during the peak 15-min period. The peak hour factor used should be based on local traffic peaking trends.

Geometric Design Data

This subpart describes the geometric design data listed in Exhibit 17-5. These data describe the geometric elements of the segment or intersections that are addressed in the automobile methodology.

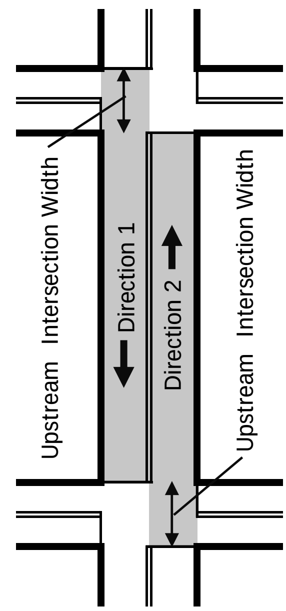
Number of Lanes

The number of lanes at the boundary intersection represents the count of lanes that are provided for each intersection traffic movement. For a turn movement, this count represents the lanes reserved for the exclusive use of turning vehicles. Turn movement lanes include turn lanes that extend backward for the length of the segment and lanes in a turn bay. Lanes that are shared by two or more movements are included in the count of through lanes and are described as *shared lanes.* If no exclusive turn lanes are provided, then the turn movement is indicated to have 0 lanes.

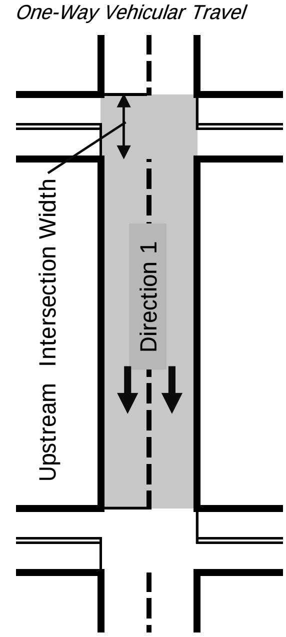
Upstream Intersection Width

The intersection width applies to the upstream boundary intersection for a given direction of travel and represents the effective width of the cross street. On a two-way street, it represents the distance between the stop (or yield) line for the two opposing segment through movements at the boundary intersection, as measured along the centerline of the segment. On a one-way street, it represents the distance from the stop line to the far side of the most distant traffic lane on the cross street.

Two-Way Vehicular Travel



One-Way Vehicular Travel



Turn Bay Length

Turn bay length represents the length of the bay at the boundary intersection for which the lanes have full width and in which queued vehicles can be stored. Bay length is measured parallel to the roadway centerline. If there are multiple lanes in the bay and they have differing lengths, then the length entered should be an average value.

If a two-way left-turn lane is provided for left-turn vehicle storage and adjacent access points exist, then the bay length entered should represent the effective storage length available to the left-turn movement. The determination of effective length is based on consideration of the adjacent access points and their associated left-turning vehicles that store in the two-way left-turn lane.

Number of Through Lanes

The number of through lanes on the segment represents the count of lanes that extend for the length of the segment and serve through vehicles (even if a lane is dropped or added at a boundary intersection). This count is specified separately for each direction of travel along the segment. A lane provided for the exclusive use of turning vehicles is not included in this count.

Number of Lanes at Access Points

The number of lanes at an access point intersection represents the count of lanes that are provided for each traffic movement at the intersection. The method for determining this number follows the same guidance provided in a previous paragraph for number of lanes at boundary intersections.

Turn Bay Length at Access Points

Turn bay length represents the length of the bay at the access point intersection for which the lanes have full width and in which queued vehicles can be stored. This length is needed for both segment approaches to the access point intersection. The method for determining this length follows the same guidance provided in a previous paragraph for turn bay length at boundary intersections.

Segment Length

Segment length represents the distance between the boundary intersections that define the segment. The point of measurement at each intersection is the stop line, the yield line, or the functional equivalent in the subject direction of travel. This length is measured along the centerline of the street. If it differs in the two travel directions, then an average length is used.

The *link length* is used in some calculations. It is computed as the segment length minus the width of the upstream boundary intersection.

Restrictive Median Length

The restrictive median length represents the length of street with a restrictive median (e.g., raised curb). This length is measured from median nose to median nose along the centerline of the street. It does not include the length of any median openings on the street.

Proportion of Segment with Curb

The proportion of the segment with curb represents that portion of the link length that has curb along the right side of the segment. This proportion is computed as the length of street with a curbed cross section divided by the link length. The length of street with a curbed cross section is measured from the start of the curbed cross section to the end of the curbed cross section on the link. The width of driveway openings is *not* deducted from this length. This value is input for each direction of travel along the segment.

Number of Access Point Approaches

The number of access point approaches along a segment represents the count of unsignalized driveway and public street approaches to the segment, regardless of the traffic demand entering the approach. This number is counted separately for each side of the segment. It must equal or exceed the number of active access points for which delay to segment through vehicles is computed. If the downstream boundary intersection is unsignalized, its cross-street approach on the right-hand side (in the direction of travel) is included in the count.

Other Data and Performance Measures

This subpart describes the data listed in Exhibit 17-5 that are categorized as "other data" or "performance measures."

Analysis Period Duration

The analysis period is the time interval considered for the performance evaluation. Its duration is in the range of 15 min to 1 h, with longer durations in this range sometimes used for planning analyses. In general, the analyst should use caution in interpreting the results from an analysis period of 1 h or more because the adverse impact of short peaks in traffic demand may not be detected. Also, if the analysis period is other than 15 min, then the peak hour factor should not be used.

The methodology was developed to evaluate conditions in which queue spillback does not affect the performance of the subject segment or either boundary intersection during the analysis period. If spillback affects performance, the analyst should consider using an alternative analysis tool that is able to model the effect of spillback conditions.

Operational Analysis. A 15-min analysis period should be used for operational analyses. This duration will accurately capture the adverse effects of demand peaks. Any 15-min period of interest can be evaluated with the methodology; however, a complete evaluation should always include an analysis of conditions during the 15-min period that experiences the highest traffic demand during a 24-h period.

If traffic demand exceeds capacity for a given 15-min analysis period, then a multiple-period analysis should be conducted. This type of analysis consists of an evaluation of several consecutive 15-min periods. The periods analyzed would include an initial analysis period that has no initial queue, one or more periods in which demand exceeds capacity, and a final analysis period that has no residual queue.

When a multiple-period analysis is used, segment performance measures are computed for each analysis period. Averaging performance measures across multiple analysis periods is not encouraged because it may obscure extreme values.

If a multiple-period analysis is used and the boundary intersections are signalized, then the procedure described in Chapter 18 should be used to guide the evaluation. When a procedure for multiple-period analysis is not provided in the chapter that corresponds to the boundary intersection configuration, the analyst should separately evaluate each period and use the residual queue from one period as the initial queue for the next period.

Planning Analysis. A 15-min analysis period is used for most planning analyses. However, hourly traffic demands are normally produced through the planning process. Thus, when 15-min forecast demands are not available for a 15-min analysis period, a peak hour factor must be used to estimate the 15-min demands for the analysis period. A 1-h analysis period can be used if appropriate. Regardless of analysis-period duration, a single-period analysis is typical for planning applications.

Speed Limit

Average running speed is used in the methodology to evaluate segment performance. It is correlated with speed limit when speed limit reflects the environmental and geometric factors that have an influence on driver speed choice. As such, speed limit represents a single input variable that can be used as a convenient way to estimate running speed while limiting the need for numerous environmental and geometric input data.

The convenience of using speed limit as an input variable comes with a caution—the analyst must not infer a cause-and-effect relationship between the input speed limit and the estimated running speed. More specifically, the computed change in performance resulting from a change in the input speed limit is not likely to be indicative of performance changes that will actually be realized. Research indicates that a change in speed limit has a proportionally smaller effect on the actual average speed (*1*).

The methodology is based on the assumption that the posted speed limit is (*a*) consistent with that found on other streets in the vicinity of the subject segment and (*b*) consistent with agency policy regarding specification of speed limits. If it is known that the posted speed limit does not satisfy these assumptions, then the speed limit value that is input to the methodology should be adjusted such that it is consistent with the assumptions.

Through Control Delay

The through control delay represents the control delay to the through movement at the downstream boundary intersection. It is computed by using the appropriate procedure provided in one of Chapters 18 to 22, depending on the type of control used at the intersection.

If the intersection procedure provides delay by lane groups and the through movement is served in two or more lane groups, then the through-movement delay is computed as the weighted sum of the individual lane-group delays, where the weight for a lane group is its proportion of through vehicles.

Through Stopped Vehicles and Second- and Third-Term Back-of-Queue Size

Three variables are needed for the calculation of stop rate. These variables are needed when the downstream boundary intersection is signalized. They apply to the through-lane group at this intersection. A procedure for computing the number of fully stopped vehicles N_f, second-term back-of-queue size Q_2, and third-term back-of-queue size Q_3 is provided in Chapter 31, Signalized Intersections: Supplemental.

If the procedure provides the stop rate by lane groups and the through movement is served in two or more lane groups, then the through-movement stop rate is computed as the weighted sum of the individual lane-group stop rates, where the weight for a lane group is its proportion of through vehicles.

Capacity

The capacity of a movement group represents the maximum number of vehicles that can discharge from a queue during the analysis period, divided by the analysis period duration. This value is needed for the movements entering the segment at the upstream boundary intersection and for the movements exiting the segment at the downstream boundary intersection. With one exception, it is computed by using the appropriate procedure provided in one of Chapters 18 to 22, depending on the type of control used at the intersection. Chapter 19, Two-Way STOP-Controlled Intersections, does not provide a procedure for estimating the capacity of the uncontrolled through movement, but this capacity can be estimated by using Equation 17-1.

Equation 17-1

$$c_{th} = 1{,}800\ (N_{th} - 1 + p^{*}_{0,j})$$

where

c_{th} = through-movement capacity (veh/h),

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

$p^{*}_{0,j}$ = probability that there will be no queue in the inside through lane.

The probability $p^{*}_{0,j}$ is computed by using Equation 19-43 in Chapter 19. It is equal to 1.0 if a left-turn bay is provided for left turns from the major street.

If the procedure in Chapters 18 to 22 provides capacity by lane groups and the through movement is served in two or more lane groups, then the through-movement capacity is computed as the weighted sum of the individual lane-group capacities, where the weight for a lane group is its proportion of through vehicles. A similar approach is used to compute the capacity for a turn movement.

Midsegment Delay and Stops

Through vehicles traveling along a segment can encounter a variety of situations that cause them to slow slightly or even come to a stop. These encounters delay the through vehicles and cause their segment running time to increase. Situations that can cause this delay include

- Vehicles turning from the segment into an access point approach,
- Pedestrians crossing at a midsegment crosswalk,
- Vehicles maneuvering into or out of an on-street parking space,
- Double-parked vehicles blocking a lane, and
- Vehicles in a dropped lane that are merging into the adjacent lane.

A procedure is provided in the methodology for estimating the delay due to vehicles turning left or right into an access point approach. This edition of the HCM does not include procedures for estimating the delay or stops due to the other sources listed. If they exist on the subject segment, they must be estimated by the analyst and input to the methodology.

Nonautomobile Modes

This part describes the input data needed for the pedestrian, bicycle, and transit methodologies. The data are listed in Exhibit 17-6 and are identified as "input data elements." They must be separately specified for each direction of travel on the segment.

Exhibit 17-6
Input Data Requirements: Nonautomobile Modes

Data Category	Location	Input Data Element	Pedestrian Mode	Bicycle Mode	Transit Mode
Traffic characteristics	Segment, transit	Dwell time			X
		Excess wait time			X
		Passenger trip length			X
		Transit frequency			X
		Passenger load factor			X
	Segment, other	Midsegment flow rate (motorized vehicles)	X	X	
		Percent heavy vehicles		X	
		Pedestrian flow rate	X		
		Prop. of on-street parking occupied	X	X	
Geometric design	Segment, roadway	Downstream intersection width	X		
		Segment length	X	X	X
		Number of through lanes	X	X	
		Width of outside through lane	X	X	
		Width of bicycle lane	X	X	
		Width of paved outside shoulder	X	X	
		Median type and curb presence	X	X	
		No. of access point approaches		X	
	Segment, sidewalk	Presence of a sidewalk	X		
		Total walkway width	X		
		Effective width of fixed objects	X		
		Buffer width	X		
		Spacing of objects in buffer	X		
Other	Segment	Area type			X
		Pavement condition rating		X	
		Distance to nearest signal-controlled crossing	X		
		Legality of midsegment pedestrian crossing	X		
		Proportion of sidewalk adjacent to window, building, or fence	X		
	Transit stop	Transit stop location			X
		Transit stop position			X
		Proportion of stops with shelters			X
		Proportion of stops with benches			X
Performance measures	Segment	Motorized vehicle running speed	X	X	X
		Pedestrian LOS score for link			X
	Boundary intersection	Through control delay			X
		Reentry delay			X
		Effective green-to-cycle-length ratio (if signalized)			X
		Volume-to-capacity ratio (if roundabout)			X
		Pedestrian delay	X		
		Bicycle delay		X	
		Pedestrian LOS score for intersection	X		
		Bicycle LOS score for intersection		X	

Exhibit 17-6 categorizes each input data element by travel mode methodology. An "X" is used to indicate the association between a data element and methodology. A blank cell indicates that the data element is not used as input for the corresponding methodology.

The data elements listed in Exhibit 17-6 do not include variables that are considered to represent calibration factors. Default values are provided for these factors because they typically have a relatively narrow range of reasonable values or they have a small impact on the accuracy of the performance estimates. The recommended value for each calibration factor is identified at the relevant point during the presentation of the methodology.

Traffic Characteristics Data

This subpart describes the traffic characteristics data listed in Exhibit 17-6. These data describe the vehicle, pedestrian, and transit traffic streams traveling along the segment during the analysis period. If there are multiple transit routes on the segment, then the transit-related variables are needed for each route.

Dwell Time

Dwell time represents the time that the transit vehicle is stopped at the curb to serve passenger movements, including the time required to open and close the doors. It does not include time spent stopped after passenger movements have ceased (e.g., waiting for a traffic signal or waiting for a gap in traffic to reenter the travel lane). Dwell times are typically in the range of 10 to 60 s, depending on boarding and alighting demand. Procedures for measuring and estimating dwell time are provided in the *Transit Capacity and Quality of Service Manual* (*3*).

Excess Wait Time

The scheduled departure time from a stop and the scheduled travel time for a trip set the baseline for a passenger's expectations for how long a trip should take. If the transit vehicle departs late—or worse, departs before the scheduled time (i.e., before all the passengers planning to take that vehicle have arrived at the stop)—the trip will likely take longer than planned, which negatively affects a passenger's perceptions of the quality of service.

Transit reliability is measured by *excess wait time,* the average number of minutes passengers must wait at a stop past the scheduled departure time. It is measured in the field as the sum of the differences between the scheduled and actual departure times at the preceding time point, divided by the number of transit vehicle arrivals. Early departures from the preceding time point are treated as the transit vehicle being one headway late, as a passenger arriving at the stop by the scheduled departure time would have to wait one headway for the next transit vehicle. If time point–specific excess wait time information is not available, but on-time performance (e.g., percentage of departures from a time point 0 to 5 min late) data are available for a route, then Section 2, Methodology, provides a procedure for estimating excess wait time from on-time performance.

Passenger Trip Length

The impact of a late transit vehicle departure on the overall passenger speed for a trip (as measured by using scheduled departure time to actual arrival time) depends on the length of the passenger's trip. For example, a departure 5 min late has more of a speed impact on a 1-mi-long trip than on a 10-mi-long trip. Average passenger trip length is used to determine the impact of late departures on overall trip speed. For most purposes, the average trip length can be determined from National Transit Database data for the transit agency (*4*) by dividing total passenger-miles by total unlinked trips. However, if an analyst has reason to believe that average trip length on a route is substantially different from the system average, a route-specific value can be determined from automatic passenger counter data or National Transit Database count sheets for the route by dividing total passenger-miles by the total number of boarding passengers.

Transit Frequency

Transit frequency is defined as the count of scheduled fixed-route transit vehicles that stop on or near the segment during the analysis period. It is expressed in units of transit vehicles per hour.

Scheduled transit vehicles can be considered “local” or “nonlocal.” Local transit vehicles make regular stops along the street (typically every 0.25 mi or less), although they do not necessarily stop within the analysis segment when segment lengths are short or when stops alternate between the near and far sides of boundary intersections. They are always counted, regardless of whether they stop within the subject segment. Nonlocal transit vehicles operate on routes with longer stop spacing than local routes (e.g., limited-stop, bus rapid transit, or express routes). They are only counted when they stop within the subject segment.

Passenger Load Factor

The load factor represents the number of passengers occupying the transit vehicle divided by the number of seats on the vehicle. If the number of passengers equals the number of seats, then the load factor equals 1.0. This factor should be measured in the field or obtained from the agency serving the transit route. It is an average value for all of the scheduled fixed-route transit vehicles that travel along the segment during the analysis period.

Midsegment Flow Rate

The midsegment flow rate of motorized vehicles is equivalent to the midsegment flow rate defined previously for the automobile mode.

Percent Heavy Vehicles

A heavy vehicle is defined as any vehicle with more than four tires touching the pavement. Local buses that stop within the intersection area are not included in the count of heavy vehicles. The percentage of heavy vehicles represents the count of heavy vehicles that arrive during the analysis period divided by the total vehicle count for the same period. This percentage is provided for the same location on the segment as represented by the midsegment flow rate.

Pedestrian Flow Rate

The pedestrian flow rate is based on the count of pedestrians traveling along the outside of the subject segment during the analysis period. A separate count is taken for each direction of travel along the side of the segment. Each count is divided by the analysis period duration to yield a directional hourly flow rate. These rates are then added to obtain the pedestrian flow rate for that side.

Proportion of On-Street Parking Occupied

This variable represents the proportion of the segment's right-hand curb line on which parked vehicles are present during the analysis period. It is computed as the sum of the curb-line lengths occupied by parked vehicles divided by the link length. Also, the use of pavement markings to delineate the parking lane should be noted.

If parking is not allowed on the segment, then the proportion equals 0.0. If parking is allowed along the segment but the spaces are not used during the analysis period, then the proportion equals 0.0. If parking is allowed along the full length of the segment but only one-half of the spaces are occupied during the analysis period, then the proportion equals 0.50.

Geometric Design Data

This subpart describes the geometric design data listed in Exhibit 17-6. These data describe the geometric elements that influence pedestrian, bicycle, or transit performance. All input data should be representative of the segment for its entire length. An average value should be used for each element that varies along the segment. Segment length, number of through lanes, and number of access point approaches are defined previously for the automobile mode.

Downstream Intersection Width

The intersection width applies to the downstream boundary intersection for a given direction of travel and represents the effective width of the cross street. On a two-way street, it represents the distance between the stop (or yield) line for the two opposing segment through movements at the boundary intersection, as measured along the centerline of the segment. On a one-way street, it represents the distance from the stop line to the far side of the most distant traffic lane on the cross street.

Width of Outside Through Lane, Bicycle Lane, and Paved Outside Shoulder

The widths of several individual elements of the cross section are considered input data. These elements include the outside lane that serves motorized vehicles traveling along the segment, the bicycle lane adjacent to the outside lane (if used), and the outside shoulder. The outside shoulder may be used for on-street parking. The width of each of these elements is mutually exclusive because they are adjacent (i.e., not overlapped) in the cross section.

The outside lane width does not include the width of the gutter. If curb and gutter are present, then the width of the gutter is included in the shoulder width (i.e., shoulder width is measured to the curb face when a curb is present).

Median Type and Curb Presence

The median type is designated as undivided, nonrestrictive (e.g., two-way left-turn lane), or restrictive (e.g., raised curb). Whether the cross section has curb on the outside edge of the roadway should also be noted.

Presence of a Sidewalk

A sidewalk is a paved walkway that is provided at the side of the roadway. It is assumed that pedestrians will walk in the street if a sidewalk is not present.

Total Walkway Width

Total walkway width is measured from the outside edge of the road pavement (or face of curb, if present) to the far edge of the sidewalk (as sometimes delineated by a building face or landscaping). It includes the width of any buffer (see below), if present. If this width varies along the segment, then an average value is used. A paved shoulder is not included in this width measurement.

Effective Width of Fixed Objects

Two input variables are used to describe fixed objects along the walkway. One variable represents the effective width of objects along the inside of the sidewalk. These objects include light poles, traffic signs, planter boxes, and so forth. Typical widths for these objects are provided in Chapter 23, Off-Street Pedestrian and Bicycle Facilities. All objects along the sidewalk should be considered and an average value for the length of the sidewalk input to the methodology.

The second variable represents the effective width of objects along the outside of the sidewalk. It is determined in the same manner as was the first variable.

Buffer Width and Spacing of Objects in Buffer

The buffer width represents the distance between the outside edge of the paved roadway (or face of curb, if present) and the near edge of the sidewalk. This element of the cross section is not designed for use by pedestrians or motorized vehicles. It may be unpaved or include various vertical objects that are continuous (e.g., barrier) or discontinuous (e.g., trees, bollards) to prevent pedestrian use. If vertical objects are in the buffer, then the average spacing of those objects that are 3 ft or more in height should also be recorded.

Other Data

This subpart describes the data listed in Exhibit 17-6 that are categorized as “other data.”

Area Type

Area type describes the environment in which the subject segment is located. This data element is used in the transit methodology to set a baseline for passenger expectations of typical transit travel speeds. For this application, it is sufficient to indicate whether the area type is a “central business district of a metropolitan area with over 5 million persons” or “other.”

Pavement Condition Rating

The pavement condition rating describes the road surface in terms of ride quality and surface defects. It is based on the Present Serviceability Rating, a subjective rating system based on a scale of 0 to 5 (*5*). Exhibit 17-7 provides a description of pavement conditions associated with various ratings.

Distance to Nearest Signal-Controlled Crossing

This input variable is needed if there is an identifiable pedestrian path (*a*) that intersects the segment and continues on beyond the segment and (*b*) on which most crossing pedestrians travel. This variable defines the distance pedestrians must travel along the segment should they divert from the path to cross the segment at the nearest signalized crossing. The crossing will typically be at a signalized intersection. However, it may also be at a signalized crosswalk provided at a midsegment location. If the crossing is at a signalized intersection, it will likely occur in the crosswalk on the side of the intersection that is nearest to the segment. Occasionally, it will be on the far side of the intersection because the near-side crosswalk is closed (or a crossing at this location is otherwise prohibited). This distance is measured along one side of the subject segment; the methodology accounts for the return distance once the pedestrian arrives at the other side of the segment.

Exhibit 17-7
Pavement Condition Rating

Pavement Condition Rating	Pavement Description	Motorized Vehicle Ride Quality and Traffic Speed
4.0 to 5.0	New or nearly new superior pavement. Free of cracks and patches.	Good ride.
3.0 to 4.0	Flexible pavements may begin to show evidence of rutting and fine cracks. Rigid pavements may begin to show evidence of minor cracking.	Good ride.
2.0 to 3.0	Flexible pavements may show rutting and extensive patching. Rigid pavements may have a few joint fractures, faulting, or cracking.	Acceptable ride for low-speed traffic but barely tolerable for high-speed traffic.
1.0 to 2.0	Distress occurs over 50% or more of the surface. Flexible pavement may have large potholes and deep cracks. Rigid pavement distress includes joint spalling, patching, and cracking.	Pavement deterioration affects the speed of free-flow traffic. Ride quality not acceptable.
0.0 to 1.0	Distress occurs over 75% or more of the surface. Large potholes and deep cracks exist.	Passable only at reduced speed and considerable rider discomfort.

Legality of Midsegment Pedestrian Crossing

This input indicates whether a pedestrian can cross the segment at any point along its length, regardless of location. If it is illegal to make this crossing at any point, then the pedestrian is assumed to be required to divert to the nearest signalized intersection to cross the segment.

Proportion of Sidewalk Adjacent to Window, Building, or Fence

Three proportions are input for a sidewalk. One proportion represents the length of sidewalk adjacent to a fence or low wall divided by the length of the link. The second proportion represents the length of the sidewalk adjacent to a building face divided by the length of the link. The final proportion represents the length of the sidewalk adjacent to a window display divided by the length of the link.

Transit Stop Location

This input describes whether a transit stop is located on the near side of a boundary intersection or elsewhere. A portion of the time required to serve a near-side transit stop at a boundary intersection may overlap with the control delay incurred at the intersection.

Transit Stop Position

Transit stops can be either *on-line*, where the bus stops entirely or mostly in the travel lane and does not have to yield to other vehicles upon exiting the stop, or *off-line,* where the bus pulls out of the travel lane to serve the stop and may have to yield to other vehicles upon exiting.

Proportion of Stops with Shelters and with Benches

These two input data describe the passenger amenities provided at a transit stop. A sheltered stop provides a structure with a roof and three enclosed sides that protect occupants from wind, rain, and sun. A shelter with a bench is counted twice, once as a shelter and a second time as a bench.

Performance Measures

This subpart describes the data listed in Exhibit 17-6 that are categorized as "performance measures." The through control delay variable was previously described for the automobile mode (in Exhibit 17-5).

Motorized Vehicle Running Speed

The motorized vehicle running speed is used in all of the nonautomobile methodologies. It is based on the segment running time obtained from the automobile methodology. The running speed is equal to the segment length divided by the segment running time.

Pedestrian LOS Score for Link

The pedestrian LOS score for the link is used in the transit methodology. It is obtained from the pedestrian methodology in this chapter.

Reentry Delay

The final component of transit vehicle stop delay is the reentry delay, the time (in seconds) a transit vehicle spends waiting for a gap to reenter the adjacent traffic stream. Reentry delay is estimated as follows (*3*):

- Reentry delay is zero at on-line stops.
- At off-line stops away from the influence of a signalized intersection queue, reentry delay is estimated from the procedures of Chapter 19, Two-Way STOP-Controlled Intersections, as if the bus were making a right turn onto the link, but a critical headway of 7 s is used to account for the slower acceleration of buses.

- At an off-line bus stop located within the influence of a signalized intersection queue, reentry delay is estimated from the queue service time, g_s, by using the procedures of Chapter 18, Signalized Intersections.

Reentry delay can be reduced by the presence of yield-to-bus laws or placards (and motorist compliance with them), the existence of an acceleration lane or queue jump departing a stop, or a higher-than-normal degree of bus driver aggressiveness in forcing buses back into the traffic stream. Analyst judgment and local data can be used to make appropriate adjustments to reentry delay in these cases.

Effective Green-to-Cycle-Length Ratio

The effective green-to-cycle-length ratio for the through movement is used in the transit methodology when the boundary intersection is a traffic signal and has a near-side transit stop. It is obtained from the Chapter 18 methodology.

Volume-to-Capacity Ratio (If Roundabout)

If the boundary intersection is a roundabout and it has a near-side transit stop, then the volume-to-capacity ratio for the rightmost lane of the segment approach to the roundabout is needed. It is obtained from the Chapter 21 methodology.

Pedestrian Delay

Three pedestrian delay variables are needed. The first is the delay to pedestrians who travel through the boundary intersection along a path that is parallel to the segment centerline. The pedestrian movement of interest is traveling on the subject side of the street and heading in a direction that is "with" or "against" the motorized traffic stream. For a two-way STOP-controlled boundary intersection, this delay is reasoned to be negligible. For a signal-controlled boundary intersection, the procedure described in Chapter 18 is used to compute this delay.

The second delay variable needed describes the delay incurred by pedestrians who cross the subject segment at the *nearest* signal-controlled crossing. If the nearest crossing is at a signalized intersection, then the procedure described in Chapter 18 is used to compute this delay. If the nearest crossing is at a midsegment signalized crosswalk, then this delay should equal the pedestrian's average wait for service after pressing the pedestrian push button. This wait will depend on the signal settings and could range from 5 to 25 s/pedestrian (s/p).

The third delay variable needed is the pedestrian waiting delay. This delay is incurred when pedestrians wait at an uncontrolled crossing location. If this type of crossing is legal, then the pedestrian waiting delay is determined by using the procedure in Chapter 19, Two-Way STOP-Controlled Intersections. If it is illegal, then the pedestrian waiting delay does not need to be calculated.

Bicycle Delay

Bicycle delay is the delay to bicyclists who travel through the boundary intersection along a path that is parallel to the segment centerline. The bicycle movement of interest is traveling on the subject side of the street and heading in the same direction as motorized vehicles. For a two-way STOP-controlled boundary intersection, this delay is reasoned to be negligible. For a signal-controlled boundary intersection, the procedure described in Chapter 18 is used to compute this delay.

Pedestrian LOS Score for Intersection

The pedestrian LOS score for the signalized intersection is used in the pedestrian methodology. It is obtained from the pedestrian methodology in Chapter 18.

Bicycle LOS Score for Intersection

The bicycle LOS score for the signalized intersection is used in the bicycle methodology. It is obtained from the bicycle methodology in Chapter 18.

SCOPE OF THE METHODOLOGY

Four methodologies are presented in this chapter. One methodology is provided for each of the automobile, pedestrian, bicycle, and transit modes. This section identifies the conditions for which each methodology is applicable.

- **Signalized and two-way STOP-controlled boundary intersections.** All methodologies can be used to evaluate segment performance with signalized or two-way STOP-controlled boundary intersections. In the latter case, the cross street is STOP controlled. The automobile methodology can also be used to evaluate performance with all-way STOP- or YIELD-controlled (e.g., roundabout) boundary intersections.
- **Arterial and collector streets.** The four methodologies were developed with a focus on arterial and collector street conditions. If a methodology is used to evaluate a local street, then the performance estimates should be carefully reviewed for accuracy.
- **Steady flow conditions.** The four methodologies are based on the analysis of steady traffic conditions and, as such, are not well suited to the evaluation of unsteady conditions (e.g., congestion, queue spillback, signal preemption).
- **Target road users.** Collectively, the four methodologies were developed to estimate the LOS perceived by automobile drivers, pedestrians, bicyclists, and transit passengers. They were not developed to provide an estimate of the LOS perceived by other road users (e.g., commercial vehicle drivers, automobile passengers, delivery truck drivers, or recreational vehicle drivers). However, it is likely that the perceptions of these other road users are reasonably well represented by the road users for whom the methodologies were developed.
- **Target travel modes.** The automobile methodology addresses mixed automobile, motorcycle, truck, and transit traffic streams in which the automobile represents the largest percentage of all vehicles. The pedestrian, bicycle, and transit methodologies address travel by walking, bicycle, and transit vehicle, respectively. The transit methodology is

limited to the evaluation of public transit vehicles operating in mixed or exclusive traffic lanes and stopping along the street. The methodologies are not designed to evaluate the performance of other travel means (e.g., grade-separated rail transit, golf carts, or motorized bicycles).

- **Influences in the right-of-way.** A road user's perception of quality of service is influenced by many factors inside and outside of the urban street right-of-way. However, the methodologies in this chapter were specifically constructed to exclude factors that are outside of the right-of-way (e.g., buildings, parking lots, scenery, or landscaped yards) that might influence a traveler's perspective. This approach was followed because factors outside of the right-of-way are not under the direct control of the agency operating the street.
- **Mobility focus for automobile methodology.** The automobile methodology is intended to facilitate the evaluation of mobility. Accessibility to adjacent properties by way of automobile is not directly evaluated with this methodology. Regardless, a segment's accessibility should also be considered in evaluating its performance, especially if the segment is intended to provide such access. Oftentimes, factors that favor mobility reflect minimal levels of access and vice versa.
- **"Typical pedestrian" focus for pedestrian methodology.** The pedestrian methodology is not designed to reflect the perceptions of any particular pedestrian subgroup, such as pedestrians with disabilities. As such, the performance measures obtained from the methodology are not intended to be indicators of a sidewalk's compliance with U.S. Access Board guidelines related to the Americans with Disabilities Act requirements. For this reason, they should not be considered as a substitute for a formal compliance assessment of a pedestrian facility.

LIMITATIONS OF THE METHODOLOGY

In general, the methodologies described in this chapter can be used to evaluate the performance of most traffic streams traveling along an urban street segment. However, the methodologies do not address all traffic conditions or types of control. The inability to replicate the influence of a condition or control type in the methodology represents a limitation. This subsection identifies the known limitations of the methodologies described in this chapter. If one or more of these limitations is believed to have an important influence on the performance of a specific street segment, then the analyst should consider using alternative methods or tools.

Automobile Modes

The automobile methodology does not directly account for the effect of the following conditions on street segment operation:

- On-street parking activity along the link (note that on-street parking activity on the approach to a signalized boundary intersection is addressed in Chapter 18, Signalized Intersections),
- Significant grade along the link,

- Capacity constraints between intersections (e.g., narrow bridges),
- Queuing at the downstream boundary intersection consistently backing up to and interfering with the operation of the upstream intersection or an access point intersection,
- Stops incurred by segment through vehicles as a result of a vehicle ahead turning from the segment into an access point,
- Bicycles sharing a traffic lane with vehicular traffic, and
- Cross-street congestion or a railroad crossing that blocks through traffic.

In addition, any limitations associated with the methodologies used to evaluate the intersections that bound the urban street segment are shared with this methodology. These limitations are listed in Chapters 18 to 22.

Nonautomobile Modes

This part identifies the limitations of the pedestrian, bicycle, and transit methodologies. These methodologies are not able to model the presence of railroad crossings. In addition, the pedestrian methodology does not model the following conditions:

- Segments bounded by all-way STOP-controlled intersections or roundabouts;
- Midsegment unsignalized crosswalks;
- Grades in excess of 2%;
- Pedestrian overcrossings for service across or along the segment;
- Points of high-volume pedestrian access to a sidewalk, such as a transit stop or a doorway from a large office building; and
- Points where a high volume of vehicles cross the sidewalk, such as a parking garage entrance.

In addition, the bicycle methodology is not able to model the following conditions:

- Segments bounded by all-way STOP-controlled intersections or roundabouts, and
- Grades in excess of 2%.

With regard to the first bullet point in each of the two lists above, procedures have not been developed yet to address the effect of all-way STOP control or YIELD control on intersection performance from a pedestrian or bicyclist perspective.

2. METHODOLOGY

OVERVIEW

This section describes four methodologies for evaluating the performance of an urban street segment. Each methodology addresses one possible travel mode within the street right-of-way. Analysts should choose the combination of methodologies that are appropriate for their analysis needs.

A complete evaluation of segment operation includes the separate examination of performance for all relevant travel modes for each travel direction. The performance measures associated with each mode and travel direction are assessed independently of one another. They are not mathematically combined into a single indicator of segment performance. This approach ensures that all performance impacts are considered on a mode-by-mode and direction-by-direction basis.

The focus of each methodology in this chapter is the segment. Methodologies for quantifying the performance of the downstream boundary intersection are described in other chapters (i.e., Chapters 18 to 22). The methodology described in Chapter 16, Urban Street Facilities, can be used to combine the performance measures (for a specified travel mode) on successive segments into an overall measure of facility performance for each mode and travel direction.

AUTOMOBILE MODE

This subsection provides an overview of the methodology for evaluating urban street segment performance from the motorist's perspective. The methodology is computationally intense and requires software to implement. The intensity stems from the need to model the traffic movements that enter or exit the segment in terms of their interaction with each other and with the traffic control elements of the boundary intersection. Default values are provided in Section 3, Applications, to support planning analyses for which the required input data are not available.

A Quick Estimation Method for evaluating segment performance at a planning level of analysis is provided in Chapter 30, Urban Street Segments: Supplemental. This method is not computationally intense and can be applied by using hand calculations.

The methodology is used to evaluate automobile performance on an urban street segment. Each travel direction along the segment is separately evaluated. *Unless otherwise stated, all variables are specific to the subject direction of travel.*

The methodology has been developed to evaluate automobile performance for a street segment bounded by intersections that can have a variety of control types. The focus of the discussion in this subsection is on the use of the methodology to evaluate a coordinated signal system because this type of control is the most complex. However, as appropriate, the discussion is extended to describe how key elements of this methodology can be used to evaluate automobile performance in noncoordinated systems.

Because of the intensity of the computations for coordinated–actuated control, the objective of this subsection is to introduce the analyst to the calculation process and to discuss the key analytic procedures. This objective is achieved by outlining the procedures that make up the methodology while highlighting important equations, concepts, and interpretations. A more detailed discussion of these procedures is provided in Chapter 30, Urban Street Segments: Supplemental.

The computational engine developed by the Transportation Research Board Committee on Highway Capacity and Quality of Service represents the most detailed description of this methodology. Additional information about this engine is provided in Chapter 30.

Framework

Exhibit 17-8 illustrates the calculation framework of the automobile methodology. It identifies the sequence of calculations needed to estimate selected performance measures. The calculation process is shown to flow from top to bottom in the exhibit. These calculations are described more fully in the remainder of this subsection.

The framework illustrates the calculation process as applied to two system types: coordinated and noncoordinated. The analysis of coordinated systems recognizes the influence of an upstream signalized intersection on the performance of the street segment. The analysis of noncoordinated systems is based on the assumption that arrivals to a boundary intersection are random.

The framework is further subdivided into the type of traffic control used at the intersections that bound the segment. This approach recognizes that a boundary intersection can be signalized, two-way STOP-controlled, all-way STOP-controlled, or a roundabout. Although not indicated in the exhibit, the boundary intersection could also be an interchange ramp terminal.

There is reference in Exhibit 17-8 to various procedures described in Chapters 18, 20, and 21. With regard to Chapter 18, the procedure for computing actuated phase duration is needed for the analysis of actuated intersections on both coordinated and noncoordinated segments. Also, the procedure for computing control delay in Chapter 18 is needed for the estimation of segment through-movement delay. The delay estimation procedure for roundabouts and all-way STOP-controlled intersections is needed from their respective chapters for the analysis of noncoordinated segments.

Performance measures estimated for each segment travel direction include

- Travel speed,
- Stop rate, and
- Automobile traveler perception score.

The perception score is derived from traveler perception research and is an indication of travelers' relative satisfaction with service provided along the segment.

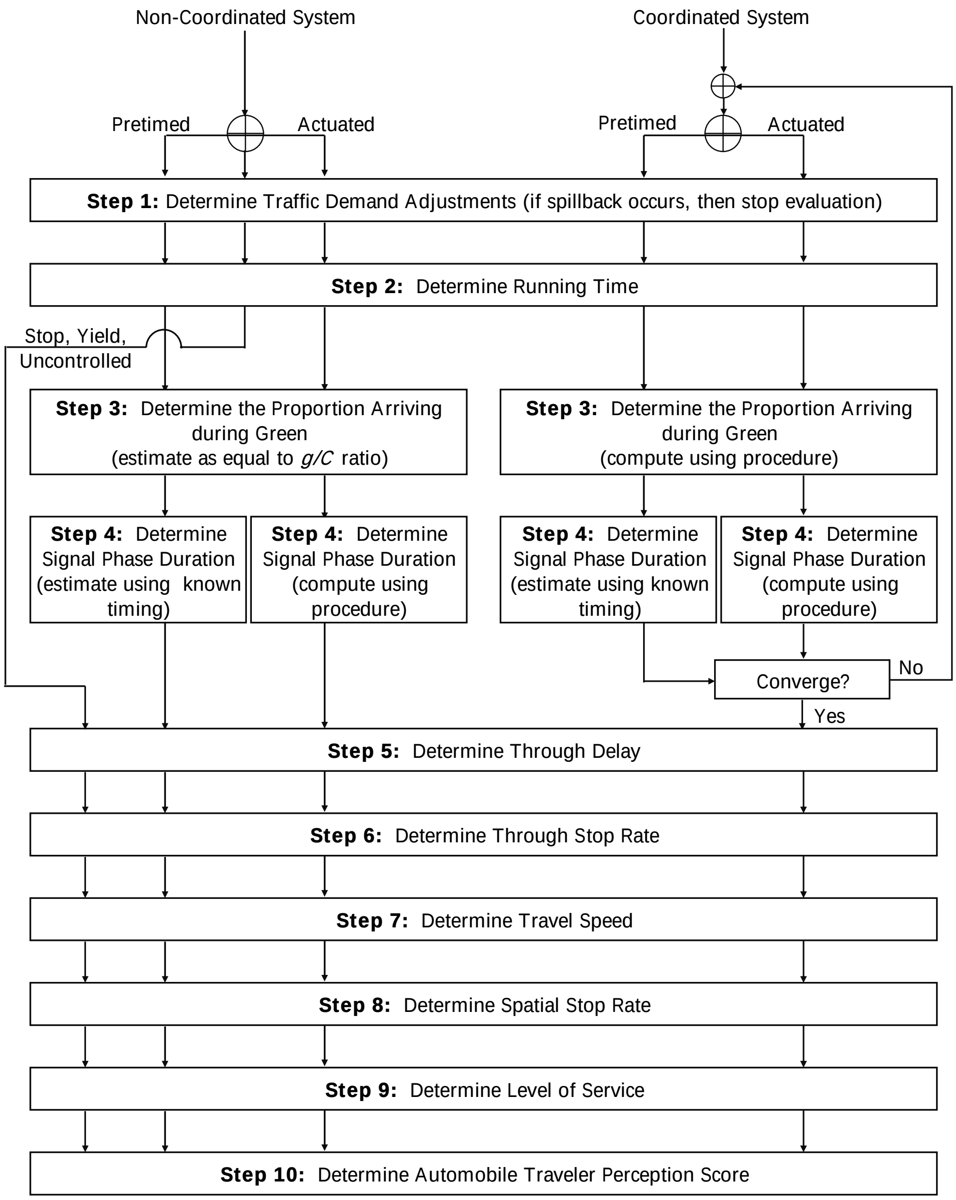


Exhibit 17-8
Automobile Methodology for Urban Street Segments

Step 1: Determine Traffic Demand Adjustments

During this step, various adjustments are undertaken to ensure the volumes evaluated accurately reflect segment traffic conditions. The adjustments include (*a*) limiting entry to the segment due to capacity constraint, (*b*) balancing the volumes entering and exiting the segment, and (*c*) mapping entry-to-exit flow paths by using an origin–destination matrix. Also during this step, a check is made for the occurrence of spillback from a turn bay or from one segment into another segment. As indicated in Exhibit 17-8, the evaluation should not proceed if spillback occurs because the methodology does not address this condition.

The procedures for making these adjustments and checks are described in Chapter 30. These adjustments and checks are not typically used for planning and preliminary engineering analyses.

Capacity Constraint

When the demand volume for an intersection traffic movement exceeds its capacity, the discharge volume from the intersection is restricted (or metered). When this metering occurs for a movement that enters the subject segment, the volume arriving at the downstream signal is reduced below the unrestricted value.

To determine whether metering occurs, the capacity of each upstream movement that discharges into the subject segment must be computed and then checked against the associated demand volume. If this volume exceeds movement capacity, then the volume entering the segment must be reduced to equal the movement capacity.

Volume Balance

Volume balance describes a condition in which the combined volume from all movements entering a segment equals the combined volume exiting the segment, in a given direction of travel. The segment is balanced when entering volume equals exit volume for both directions of travel. Unbalanced volumes often exist in turn movement counts when the count at one intersection is taken at a different time than the count at the adjacent intersection. They are also likely to exist when access point intersections exist but their volume is not counted.

The accuracy of the performance evaluation may be adversely affected if the volumes are not balanced. The extent of the impact is based on the degree to which the volumes are unequal. To balance the volumes, the methodology assumes that the volume for each movement entering the segment is correct and adjusts the volume for each movement exiting the segment in a proportional manner such that a balance is achieved. The exiting volumes computed in this manner represent a best estimate of the actual *demand* volumes, such that the adjustment process does not preclude the possibility of queue buildup by one or more exit movements at the downstream boundary intersection during the analysis period.

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.

The concept of an origin–destination distribution matrix is illustrated by example. Consider the segment shown in Exhibit 17-9. There are three entry volumes at upstream Intersection A that contribute to three exit volumes at downstream Intersection B. There is also an entrance and exit volume at the access point intersection located between the two intersections. It should be noted that 1,350 veh/h enter the segment and 1,350 veh/h exit the segment; thus there is volume balance for this example segment. The origin–destination distribution matrix for this sample street segment is shown in Exhibit 17-10.

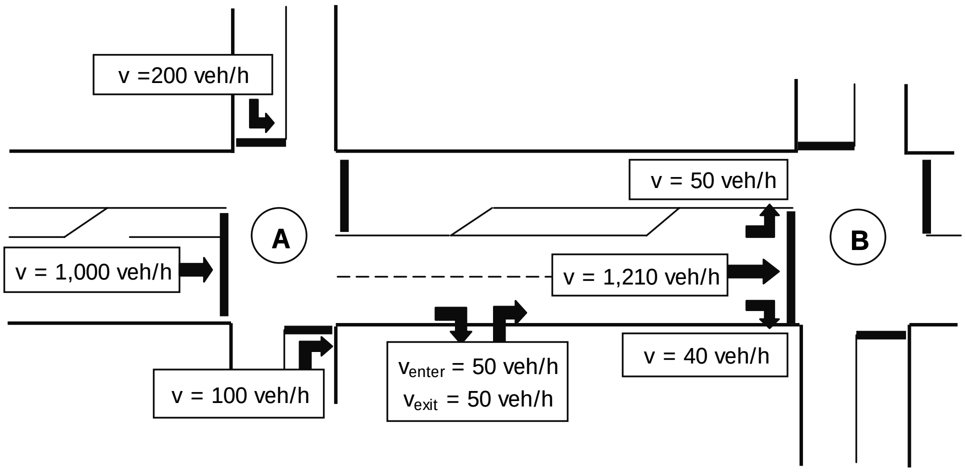


Exhibit 17-9
Entry and Exit Volume on Example Segment

Exhibit 17-10
Example Origin–Destination Distribution Matrix

Origin Volume by Movement (veh/h)				Destination Volume	
Left	**Through**	**Right**	**Access Point**	**Movement**	**Total Volume (veh/h)**
2	46	2	0	Left	50
188	877	95	50	Through	1,210
3	36	1	0	Right	40
7	41	2	0	Access Point	50
200	1,000	100	50		1,350

The column totals in the last row of Exhibit 17-10 correspond to the entry volumes shown in Exhibit 17-9. The row totals in the last column of Exhibit 17-10 indicate the exit volumes. The individual cell values indicate the volume contribution of each upstream movement to each downstream movement. For example, of the 1,000 through vehicles that enter the segment, 877 depart the segment as a through movement, 46 depart as a left-turn movement, and so on. The volumes in the individual cells are sometimes expressed as a proportion of the column total.

The automobile methodology computes one origin–destination matrix for movements between the upstream boundary intersection and a downstream junction (i.e., either an access point or the downstream boundary intersection). When the boundary intersections are signalized, the matrix for movements between the upstream and downstream boundary intersections is used to compute the proportion of vehicles arriving during the green indication for each exit movement. The matrix for movements between the upstream boundary intersection and a downstream access point is used to compute the proportion of time that a platoon is passing through the access point and effectively blocking nonpriority movements from entering or crossing the street.

Spillback Occurrence

Segment spillback can be characterized as one of two types: cyclic and sustained. Cyclic spillback occurs when the downstream boundary intersection is signalized and its queue backs into the upstream intersection as a result of queue growth during the red indication. When the green indication is presented, the queue dissipates and spillback is no longer present for the remainder of the cycle.

This type of spillback can occur on short street segments with relatively long signal cycle lengths.

Sustained spillback occurs at some point during the analysis period and is a result of oversaturation (i.e., more vehicles discharging from the upstream intersection than can be served at the subject downstream intersection). The queue does not dissipate at the end of each cycle. Rather, it remains present until the downstream capacity is increased or the upstream demand is reduced.

The preceding discussion has focused on segment spillback; however, the concepts are equally applicable to turn bay spillback. In this case, the queue of turning vehicles exceeds the bay storage and spills back into the adjacent lane that is used by other vehicular movements. The occurrence of both segment and bay spillback must be checked during this step.

Use of this methodology to evaluate segments (or intersection turn bays) with significant, sustained spillback is problematic because of the associated unsteady conditions and complex interactions. The procedure described in Chapter 30 is used in this step to compute the time when sustained spillback occurs, if it occurs. If this time of occurrence is shorter than the analysis period, then the methodology may not yield accurate performance estimates. In this situation, 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.

Step 2: Determine Running Time

A procedure for determining segment running time is described in this step. This procedure includes the calculation of free-flow speed, a vehicle proximity adjustment factor, and the additional running time due to midsegment delay sources. Each calculation is discussed in the following subparts, which culminate with the calculation of segment running time.

A. Determine Free-Flow Speed

Free-flow speed represents the average running speed of through automobiles traveling along a segment under low-volume conditions and not delayed by traffic control devices or other vehicles. It reflects the effect of the street environment on driver speed choice. Elements of the street environment that influence this choice under free-flow conditions include speed limit, access point density, median type, curb presence, and segment length.

The determination of free-flow speed is based on the calculation of base free-flow speed and an adjustment factor for signal spacing. These calculations are described in the next few paragraphs, which culminate in the calculation of free-flow speed.

Base Free-Flow Speed

The base free-flow speed is defined to be the free-flow speed on longer segments. It includes the influence of speed limit, access point density, median type, and curb presence. It is computed by using Equation 17-2. Alternatively, it can be measured in the field by using the technique described in Chapter 30.

Equation 17-2

$$S_{fo} = S_0 + f_{CS} + f_A$$

where

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

S_0 = speed constant (mi/h),

f_{CS} = adjustment for cross section (mi/h), and

f_A = adjustment for access points (mi/h).

The speed constant and adjustment factors used in Equation 17-2 are listed in Exhibit 17-11. Equations provided in the table footnote can also be used to compute these adjustment factors.

Exhibit 17-11
Base Free-Flow Speed Adjustment Factors

Speed Limit (mi/h)	Speed Constant S_0 (mi/h)[a]	Median Type	Percent with Restrictive Median (%)	Adjustment for Cross Section f_{CS} (mi/h)[b] No Curb	Curb
25	37.4	Restrictive	20	0.3	-0.9
30	39.7		40	0.6	-1.4
35	42.1		60	0.9	-1.8
40	44.4		80	1.2	-2.2
45	46.8		100	1.5	-2.7
50	49.1	Nonrestrictive	Not applicable	0.0	-0.5
55	51.5	No median	Not applicable	0.0	-0.5

Access Density D_a (points/mi)	Adjustment for Access Points f_A by Lanes N_{th} (mi/h)[c] 1 Lane	2 Lanes	3 Lanes	4 Lanes
0	0.0	0.0	0.0	0.0
2	-0.2	-0.1	-0.1	0.0
4	-0.3	-0.2	-0.1	-0.1
10	-0.8	-0.4	-0.3	-0.2
20	-1.6	-0.8	-0.5	-0.4
40	-3.1	-1.6	-1.0	-0.8
60	-4.7	-2.3	-1.6	-1.2

Notes: [a] $S_0 = 25.6 + 0.47 S_{pl}$ where S_{pl} = posted speed limit (mi/h).
[b] $f_{CS} = 1.5\, p_{rm} - 0.47\, p_{curb} - 3.7\, p_{curb}\, p_{rm}$ where p_{rm} = proportion of link length with restrictive median (decimal) and p_{curb} = proportion of segment with curb on the right-hand side (decimal).
[c] $f_A = -0.078\, D_a / N_{th}$ with $D_a = 5{,}280\,(N_{ap,s} + N_{ap,o})/(L - W_i)$ where D_a = access point density on segment (points/mi); N_{th} = number of through lanes on the segment in the subject direction of travel (ln); $N_{ap,s}$ = number of access point approaches on the right side in the subject direction of travel (points); $N_{ap,o}$ = number of access point approaches on the right side in the opposing direction of travel (points); and W_i = width of signalized intersection (ft).

Adjustment for Signal Spacing

Empirical evidence suggests that a shorter segment length (when defined by signalized boundary intersections) tends to influence the driver's choice of free-flow speed (*1*). Shorter segments have been found to have a slower free-flow speed, all other factors being the same. Equation 17-3 is used to compute the value of an adjustment factor that accounts for this influence.

Equation 17-3

$$f_L = 1.02 - 4.7 \frac{S_{fo} - 19.5}{\max(L_s, 400)} \quad \leq 1.0$$

where

f_L = signal spacing adjustment factor,

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

L_s = distance between adjacent signalized intersections (ft).

Equation 17-3 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.

Free-Flow Speed

Free-flow speed is computed by using Equation 17-4 on the basis of estimates of base free-flow speed and the signal spacing adjustment factor. Alternatively, it can be entered directly by the analyst. It can also be measured in the field by using the technique described in Chapter 30.

Equation 17-4

$$S_f = S_{fo} f_L$$

where S_f equals the free-flow speed (mi/h) and other variables are as previously defined.

B. Compute Adjustment for Vehicle Proximity

The proximity adjustment factor adjusts the free-flow running time to account for the effect of traffic density. The adjustment results in an increase in running time (and corresponding reduction in speed) with an increase in volume. The reduction in speed is a result of shorter headways associated with the higher volume and drivers' propensity to be more cautious when headways are short. Equation 17-5 is used to compute the proximity adjustment factor.

Equation 17-5

$$f_v = \frac{2}{1 + \left(1 - \frac{v_m}{52.8\ N_{th}\ S_f}\right)^{0.21}}$$

where

f_v = proximity adjustment factor,

v_m = midsegment demand flow rate (veh/h),

N_{th} = number of through lanes on the segment in the subject direction of travel (ln), and

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

The relationship between running speed [= (3,600 L)/(5,280 t_R), where L is the segment length in feet and t_R is the segment running time in seconds] and volume for an urban street segment is shown in Exhibit 17-12. Trend lines are shown for three specific free-flow speeds. At a flow rate of 1,000 vehicles per hour per lane (veh/h/ln), each trend line shows a reduction of about 2.5 mi/h relative to the free-flow speed. The trend lines extend beyond 1,000 veh/h/ln. However, it is unlikely that a volume in excess of this amount will be experienced on a segment bounded by intersections at which the through movement is regulated by a traffic control device.

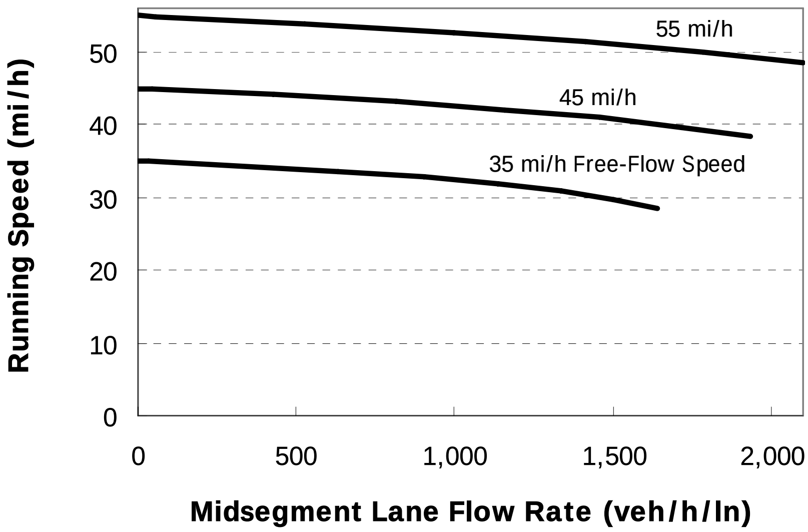


Exhibit 17-12
Speed–Flow Relationship for Urban Street Segments

LIVE GRAPH
Click here to view

C. Compute Delay due to Turning Vehicles

Vehicles turning from the subject street segment into an access point approach can cause a delay to following through vehicles. 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 intersection. Delay due to left-turning vehicles 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. A procedure for computing this delay at each access point intersection is described in Chapter 30.

For planning and preliminary engineering analyses, Exhibit 17-13 can be used to estimate the delay due to turning vehicles at one representative access point intersection by using a midsegment volume that is typical for all such access points. The values in the exhibit represent the delay to through vehicles due to left and right turns at one access point intersection. The selected value is multiplied by the number of access point intersections on the segment to estimate delay due to left and right turns (= $\sum d_{ap}$ in Equation 17-6).

Exhibit 17-13
Delay due to Turning Vehicles

Midsegment Volume (veh/h/ln)	Through Vehicle Delay (s/veh/pt) by Number of Through Lanes		
	1 Lane	2 Lanes	3 Lanes
200	0.04	0.04	0.05
300	0.08	0.08	0.09
400	0.12	0.15	0.15
500	0.18	0.25	0.15
600	0.27	0.41	0.15
700	0.39	0.72	0.15

The values listed in Exhibit 17-13 represent 10% left turns and 10% right turns from the segment at the access point intersection. If the actual turn percentages are less than 10%, then the delays can be reduced proportionally. For example, if the subject access point has 5% left turns and 5% right turns, then the values listed in the exhibit should be multiplied by 0.5 (= 5/10). Also, if a turn bay of adequate length is provided for one turn movement but not the other, then the values listed in the exhibit should be multiplied by 0.5. If both turn movements are provided a bay of adequate length, then the delay due to turns can be assumed to equal 0.0 seconds per vehicle per access point (s/veh/pt).

D. Estimate Delay due to Other Sources

Numerous other factors could cause a driver to reduce speed or to incur delay while traveling along a segment. For example, a vehicle that is completing a parallel parking maneuver may cause following vehicles to incur some delay. Also, vehicles that yield to pedestrians at a midsegment crosswalk may incur delay. Finally, bicyclists riding in a traffic lane or an adjacent bicycle lane may directly or indirectly cause vehicular traffic to adopt a lower speed.

Of the many sources for midsegment delay, the automobile methodology only includes procedures for estimating the delay due to turning vehicles. However, if the delay due to other sources is known or estimated by other means, then it can be included in the equation to compute running time.

E. Compute Segment Running Time

Equation 17-6 is used to compute segment running time based on consideration of through movement control at the boundary intersection, free-flow speed, vehicle proximity, and various midsegment delay sources.

Equation 17-6

$$t_R = \frac{6.0 - l_1}{0.0025\,L} f_x + \frac{3{,}600\,L}{5{,}280\,S_f} f_v + \sum_{i=1}^{N_{ap}} d_{ap,i} + d_{\text{other}}$$

with

Equation 17-7

$$f_x = \begin{cases} 1.00 & \text{(signalized or STOP-controlled through movement)} \\ 0.00 & \text{(uncontrolled through movement)} \\ \min[v_{th}/c_{th}, 1.00] & \text{(YIELD-controlled through movement)} \end{cases}$$

where

t_R = segment running time (s);

l_1 = start-up lost time = 2.0 if signalized, 2.5 if STOP or YIELD controlled (s);

L = segment length (ft);

f_x = control-type adjustment factor;

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

c_{th} = through-movement capacity (veh/h);

$d_{ap,i}$ = delay due to left and right turns from the street into access point intersection i (s/veh);

N_{ap} = number of influential access point approaches along the segment = $N_{ap,s}$ + $p_{ap,lt} N_{ap,o}$ (points);

$N_{ap,s}$ = number of access point approaches on the right side in the subject direction of travel (points);

$N_{ap,o}$ = number of access point approaches on the right side in the opposing direction of travel (points);

$p_{ap,lt}$ = proportion of $N_{ap,o}$ that can be accessed by a left turn from the subject direction of travel; and

d_{other} = delay due to other sources along the segment (e.g., curb parking or pedestrians) (s/veh).

Other variables are as previously defined. The variables l_1, f_x, v_{th}, and c_{th} used with the first term in Equation 17-6 apply to the through movement exiting the segment at the boundary intersection. This term accounts for the time required to accelerate to the running speed, less the start-up lost time. The divisor in this term is an empirical adjustment that minimizes the contribution of this term for longer segments. It partially reflects a tendency for drivers to offset this added time by adopting slightly higher midsegment speeds than reflected in the start-up lost time estimate.

Step 3: Determine the Proportion Arriving During Green

This step applies to the downstream boundary intersection when the operation of a signalized urban street segment is evaluated. If the downstream boundary intersection is not signalized, then this step is skipped.

The methodology includes a procedure for computing the proportion of vehicles that arrive during the effective green time for a phase serving a segment lane group (i.e., the lane groups "internal" to the segment). This procedure is described in this step. The procedure described in Chapter 18, Signalized Intersections, should be used for phases serving external lane groups.

If the upstream intersection is not signalized (or it is signalized but not coordinated with the downstream boundary intersection), then the proportion arriving during the green is equal to the effective green-to-cycle-length ratio and this step is completed. This relationship implies that arrivals are effectively uniform during the cycle when averaged over the analysis period.

If the boundary intersections are coordinated, then the remaining discussion in this step applies. The calculation of the proportion arriving during green is based on the signal timing of the upstream and downstream boundary intersections. However, if the signals are actuated, then the resulting estimate of the proportion arriving during green typically has an effect on signal timing and capacity. In fact, the process is circular and requires an iterative sequence of calculations to arrive at a convergence solution in which all computed variables are in agreement with their initially assumed values. This process is illustrated in Exhibit 17-8. This exhibit indicates that the calculation of average phase duration is added to this process when the intersection is actuated.

Typically, there are three signalized traffic movements that depart the upstream boundary intersection at different times during the signal cycle. They are the cross-street right turn, major-street through, and cross-street left turn. Traffic may also enter the segment at various access point intersections. The signalized movements often enter the segment as a platoon, but this platoon disperses as the vehicles move down the segment.

A platoon dispersion model is used to predict the dispersed flow rate as a function of running time at any specified downstream location. The dispersed flow rates for the upstream intersection movement are combined with access point flow rates to predict an arrival flow profile at the downstream location. Exhibit 17-14 illustrates the predicted arrival flow profile at the stop line of the downstream intersection. This profile reflects the combination of the left-turn, through, and right-turn movements from the upstream intersection plus the turn movements at the access point intersection. The platoon dispersion model and the manner in which it is used to predict the dispersed flow rates for each of the individual movements are described in Chapter 30.

The gray shaded area in Exhibit 17-14 represents the arrival count during green n_g. This count is computed by summing the flow rate for each time "step" (or interval) that occurs during the effective green period. The proportion of vehicles arriving during the effective green period for a specified lane group is computed by using Equation 17-8.

Equation 17-8

$$P = \frac{n_g}{q_d\, C}$$

where

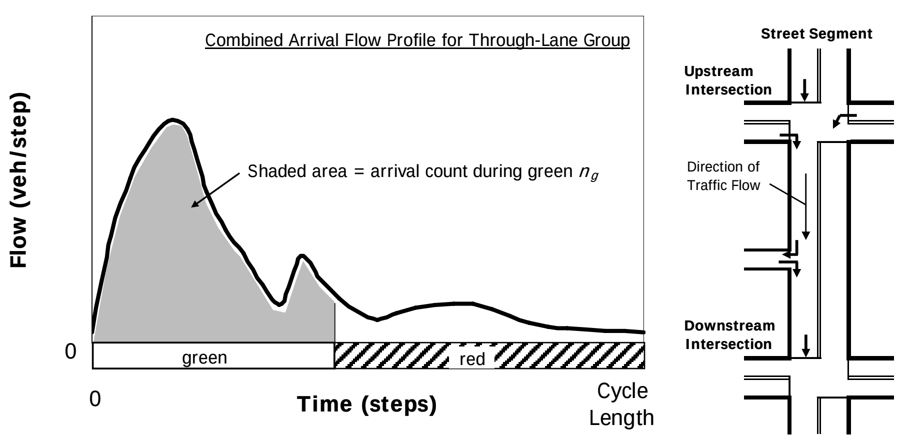
P = proportion of vehicles arriving during the green indication,

n_g = arrival count during green (veh),

q_d = arrival flow rate for downstream lane group (veh/s), and

C = cycle length (s).

Exhibit 17-14
Use of an Arrival Flow Profile to Estimate the Volume Arriving During Green



Step 4: Determine Signal Phase Duration

This step applies to the downstream boundary intersection when the operation of a signalized urban street segment is evaluated. If the downstream boundary intersection is not signalized, then this step is skipped.

If the downstream boundary intersection has pretimed signal control, then the signal phase duration is an input value. If this intersection has some form of actuated control, then the procedure described in Chapter 18 is used to estimate the average phase duration.

Steps 1 to 4 are repeated until the duration of each phase at each signalized intersection converges to its steady-state value. Convergence is indicated when the estimate of phase duration on two successive repetitions is the same.

Step 5: Determine Through Delay

The delay incurred by through vehicles as they exit the segment is the basis for travel time estimation. In this context, a through vehicle is a vehicle that enters and exits the segment as a through vehicle. The nature of the delay models used in this manual makes it difficult to separate the delay to through vehicles from the delay to nonthrough vehicles. However, these models can provide a reasonable estimate of through delay whenever the through movement is the dominant movement on the segment.

Through delay represents the sum of two delay sources. One source is the delay due to the traffic control at the boundary intersection. It is called control delay. The other delay is that due to the negotiation of intersection geometry, such as curvature. It is called geometric delay.

Procedures for computing control delay are described in the following chapters of this manual:

- Signal control (Chapter 18 or 22),
- All-way STOP control (Chapter 20), and
- YIELD control at a roundabout intersection (Chapter 21).

The analyst should refer to the appropriate chapter for guidance in estimating the through control delay for the boundary intersection. If the through movement is uncontrolled at the boundary intersection, then the through control delay is 0.0 s/veh.

The geometric delay for conventional three-leg or four-leg intersections (i.e., noncircular intersections) is considered to be negligible. In contrast, the geometric delay for a circular intersection is not negligible and should be added to the control delay to obtain the necessary through delay. A procedure for estimating geometric delay for roundabout intersections is described in Chapter 33, Roundabouts: Supplemental.

If the segment is not in a coordinated system, the through delay estimate should be based on isolated operation. The methodologies in Chapters 18 to 21 can be used to provide this estimate.

If the segment is within a coordinated signal system, then the methodology in Chapter 18 or Chapter 22 is used to determine the through delay. The upstream filtering adjustment factor is used to account for the effect of the upstream signal on the variability in arrival volume at the downstream intersection. The procedure for calculating this factor is described in Section 1 of Chapter 18.

If the through movement shares one or more lanes at a signalized boundary intersection, then the through delay is computed by using Equation 17-9.

Equation 17-9

$$d_t = \frac{d_{th}\ v_t\ N_t + d_{sl}\ v_{sl}(1-P_L) + d_{sr}\ v_{sr}(1-P_R)}{v_{th}}$$

where

d_t = through delay (s/veh),

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

d_{th} = delay in exclusive through-lane group (s/veh),

v_t = demand flow rate in exclusive through-lane group (veh/h/ln),

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

d_{sl} = delay in shared left-turn and through-lane group (s/veh),

v_{sl} = demand flow rate in shared left-turn and through-lane group (veh/h),

d_{sr} = delay in shared right-turn and through-lane group (s/veh),

v_{sr} = demand flow rate in shared right-turn and through-lane group (veh/h),

P_L = proportion of left-turning vehicles in the shared lane (decimal), 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 variables shown in Equation 17-9.

Step 6: Determine Through Stop Rate

As with control delay, through stop rate describes the stop rate of vehicles that enter and exit the segment as through vehicles. The nature of the stop rate models described in this step makes it difficult to separate the stops to through vehicles from those incurred by nonthrough vehicles. However, these models can provide a reasonable estimate of through stop rate whenever the through movement is the dominant movement on the segment.

Stop rate is defined as the average number of full stops per vehicle. A *full stop* is defined to occur at a signalized intersection when a vehicle slows to zero (or a crawl speed, if in queue) as a consequence of the change in signal indication from green to red, but not necessarily in direct response to an observed red indication. A *full stop* is defined to occur at an unsignalized intersection when a vehicle slows to zero (or a crawl speed, if in queue) as a consequence of the control device used to regulate the approach. For example, if a vehicle is in an overflow queue and requires three signal cycles to clear the intersection, then it is estimated to have three full stops (one stop for each cycle).

The stop rate for a STOP-controlled approach can be assumed to equal 1.0 stops/veh. The stop rate for an uncontrolled approach can be assumed to equal 0.0 stops/veh. The stop rate at a YIELD-controlled approach will vary with conflicting demand. It can be estimated (in stops per vehicle) as equal to the volume-to-capacity ratio of the through movement at the boundary intersection. This approach recognizes that YIELD control does not require drivers to come to a complete stop when there is no conflicting traffic.

The through stop rate at a signalized boundary intersection is computed by using Equation 17-10.

$$h = 3{,}600\left(\frac{N_f}{\min\left(1, \frac{v_{th}\ C}{N_{th}\ s\ g}\right) g\ s} + \frac{N_{th}\ Q_{2+3}}{v_{th}\ C}\right)$$

Equation 17-10

with

$$N_f = \frac{N_{f,t}\ N_t + N_{f,sl}\ (1 - P_L) + N_{f,sr}\ (1 - P_R)}{N_{th}}$$

Equation 17-11

$$s = \frac{s_t N_t + s_{sl}(1 - P_L) + s_{sr}(1 - P_R)}{N_{th}}$$

Equation 17-12

$$Q_{2+3} = \frac{(Q_{2,t} + Q_{3,t})\ N_t + (Q_{2,sl} + Q_{3,sl})\ (1 - P_L) + (Q_{2,sr} + Q_{3,sr})\ (1 - P_R)}{N_{th}}$$

Equation 17-13

where

- h = full stop rate (stops/veh),
- N_f = number of fully stopped vehicles (veh/ln),
- g = effective green time (s),
- s = adjusted saturation flow rate (veh/h/ln),
- Q_{2+3} = back-of-queue size (veh/ln),
- $N_{f,t}$ = number of fully stopped vehicles in exclusive through-lane group (veh/ln),
- $N_{f,sl}$ = number of fully stopped vehicles in shared left-turn and through-lane group (veh/ln),
- $N_{f,sr}$ = number of fully stopped vehicles in shared right-turn and through-lane group (veh/ln),
- N_{th} = number of through lanes (shared or exclusive) (ln),
- s_t = saturation flow rate in exclusive through-lane group (veh/h/ln),
- s_{sl} = saturation flow rate in shared left-turn and through-lane group with permitted operation (veh/h/ln),
- s_{sr} = saturation flow rate in shared right-turn and through-lane group with permitted operation (veh/h/ln),
- $Q_{2,t}$ = second-term back-of-queue size for exclusive through-lane group (veh/ln),
- $Q_{2,sl}$ = second-term back-of-queue size for shared left-turn and through-lane group (veh/ln),
- $Q_{2,sr}$ = second-term back-of-queue size for shared right-turn and through-lane group (veh/ln),

$Q_{3,t}$ = third-term back-of-queue size for exclusive through-lane group (veh/ln),

$Q_{3,sl}$ = third-term back-of-queue size for shared left-turn and through-lane group (veh/ln), and

$Q_{3,sr}$ = third-term back-of-queue size for shared right-turn and through-lane group (veh/ln).

Other variables are as previously defined. The procedure for computing N_f, Q_2, and Q_3 is provided in Chapter 31, Signalized Intersections: Supplemental.

The first term in Equation 17-10 represents the proportion of vehicles stopped once by the signal. For some of the more complex arrival–departure polygons that include left-turn movements operating with the permitted mode, the queue may dissipate at two or more points during the cycle. If this occurs, then $N_{f,i}$ is computed for each of the i periods between queue dissipation points. The value of N_f then equals the sum of the $N_{f,i}$ values computed in this manner.

The second term in Equation 17-10 represents the additional stops that may occur during overflow (i.e., cycle failure) conditions. The contribution of this term becomes significant when the volume-to-capacity ratio exceeds about 0.8. The full stop rate typically varies from 0.4 stops/veh at low volume-to-capacity ratios to 2.0 stops/veh when the volume-to-capacity ratio is about 1.0.

Step 7: Determine Travel Speed

Equation 17-14 is used to compute the travel speed for the subject direction of travel along the segment.

Equation 17-14

$$S_{T,seg} = \frac{3{,}600\ L}{5{,}280\ (t_R + d_t)}$$

where

$S_{T,seg}$ = travel speed of through vehicles for the segment (mi/h),

L = segment length (ft),

t_R = segment running time (s), and

d_t = through delay (s/veh).

The control delay used in Equation 17-14 is that incurred by the through-lane group at the downstream boundary intersection.

Step 8: Determine Spatial Stop Rate

Equation 17-15 is used to compute the spatial stop rate for the subject direction of travel along the segment.

Equation 17-15

$$H_{seg} = 5{,}280\ \frac{h + h_{\text{other}}}{L}$$

where

H_{seg} = spatial stop rate for the segment (stops/mi),

h = full stop rate (stops/veh),

h_{other} = full stop rate due to other sources (stops/veh), and

L = segment length (ft).

The full stop rate h used in Equation 17-15 is that incurred by the through-lane group at the downstream boundary intersection. In some situations, stops may be incurred at midsegment locations due to pedestrian crosswalks, bus stops, or turns into access point approaches. If the full stop rate associated with these other stops can be estimated by the analyst, then it can be included in the calculation by using the variable h_{other}.

Step 9: Determine LOS

LOS is determined for both directions of travel along the segment. Exhibit 17-2 lists the LOS thresholds established for this purpose. As indicated in this exhibit, LOS is defined by two performance measures. One measure is the travel speed for through vehicles, expressed as a percentage of the base free-flow speed. The second measure is the volume-to-capacity ratio for the through movement at the downstream boundary intersection.

The base free-flow speed was computed in Step 2 and the travel speed was computed in Step 7.

The volume-to-capacity ratio for the through movement at the boundary intersection is computed as the through volume divided by the through-movement capacity. This capacity is an input variable to the methodology.

The LOS attributed to each direction of travel applies to the segment, which includes both the link and the downstream boundary intersection. Chapters 18 to 22 describe LOS thresholds for the boundary intersection. The automobile methodology does not assign a LOS indicator to the link portion of the segment.

LOS is probably more meaningful as an indicator of traffic performance along a facility rather than a single street segment. A procedure for estimating facility LOS is described in Chapter 16.

Step 10: Determine Automobile Traveler Perception Score

The automobile traveler perception score for urban street segments is provided as a useful performance measure. It indicates the traveler's perception of service quality. The score is computed by using Equation 17-16 to Equation 17-21.

$$I_{a,seg} = 1 + P_{BCDEF} + P_{CDEF} + P_{DEF} + P_{EF} + P_F$$

Equation 17-16

with

$$P_{BCDEF} = \left(1 + e^{-1.1614 - 0.253\,H_{seg} + 0.3434\,P_{LTL,seg}}\right)^{-1}$$

Equation 17-17

$$P_{CDEF} = \left(1 + e^{0.6234 - 0.253\,H_{seg} + 0.3434\,P_{LTL,seg}}\right)^{-1}$$

Equation 17-18

$$P_{DEF} = \left(1 + e^{1.7389 - 0.253\,H_{seg} + 0.3434\,P_{LTL,seg}}\right)^{-1}$$

Equation 17-19

$$P_{EF} = \left(1 + e^{2.7047 - 0.253\,H_{seg} + 0.3434\,P_{LTL,seg}}\right)^{-1}$$

Equation 17-20

Equation 17-21

$$P_F = \left(1 + e^{3.8044 - 0.253\, H_{seg} + 0.3434\, P_{LTL,seg}}\right)^{-1}$$

where

$I_{a,seg}$ = automobile traveler perception score for segment;

P_{BCDEF} = probability that an individual will respond with a rating of B, C, D, E, or F;

P_{CDEF} = probability that an individual will respond with a rating of C, D, E, or F;

P_{DEF} = probability that an individual will respond with a rating of D, E, or F;

P_{EF} = probability that an individual will respond with a rating of E or F;

P_F = probability that an individual will respond with a rating of F; and

$P_{LTL,seg}$ = proportion of intersections with a left-turn lane (or bay) on the segment (decimal).

Other variables are as previously defined. The derivation of Equation 17-16 is based on the assignment of scores to each letter rating, in which a score of "1" is assigned to the rating of A (denoting "best"), "2" is assigned to B, and so on. The survey results were used to calibrate a set of models that collectively predicts the probability that a traveler will assign various rating combinations for a specified spatial stop rate and proportion of intersections with left-turn lanes. The score obtained from Equation 17-16 represents the expected (or long-run average) score for the population of travelers.

The proportion of intersections with left-turn lanes equals the number of left-turn lanes (or bays) encountered while driving along the segment divided by the number of intersections encountered. The signalized boundary intersection is counted (if it exists). All unsignalized intersections of public roads are counted. Private driveway intersections are not counted, unless they are signal controlled.

The score obtained from Equation 17-16 provides a useful indication of performance from the perspective of the traveler. Scores of 2.0 or less indicate the best perceived service, and values in excess of 5.0 indicate the worst perceived service. Although this score is closely tied to the concept of service quality, it is *not* used to determine LOS for the urban street segment.

PEDESTRIAN MODE

This subsection describes the methodology for evaluating the performance of an urban street segment in terms of its service to pedestrians.

Urban street segment performance from a pedestrian perspective is separately evaluated for each side of the street. *Unless otherwise stated, all variables identified in this section are specific to the subject side of the street.* If a sidewalk is not available for the subject side of the street, then it is assumed that pedestrians will walk in the street on that side (even if there is a sidewalk on the other side).

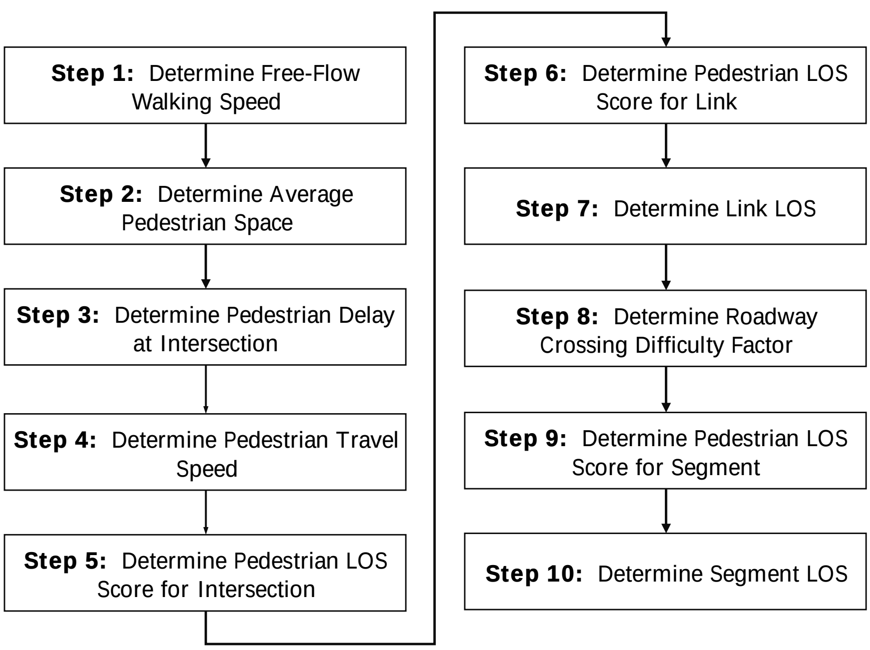
The methodology is focused on the analysis of a segment with either signal-controlled or two-way STOP-controlled boundary intersections. Chapter 18 describes a methodology for evaluating signalized intersection performance from a pedestrian perspective. No methodology exists for evaluating two-way STOP-controlled intersection performance (with the cross street STOP controlled). However, it is reasoned that this type of control has negligible influence on pedestrian service along the segment. This edition of the HCM does not include a procedure for evaluating a segment's performance when the boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The pedestrian methodology is applied through a series of nine steps that culminate in the determination of the segment LOS. These steps are illustrated in Exhibit 17-15. Performance measures that are estimated include

- Pedestrian travel speed,
- Average pedestrian space, and
- Pedestrian LOS scores for the link and segment.

A methodology for evaluating off-street pedestrian facilities is provided in Chapter 23, Off-Street Pedestrian and Bicycle Facilities.

Exhibit 17-15
Pedestrian Methodology for Urban Street Segments



Link-Based Evaluation

Steps 6 and 7 of the pedestrian methodology can be used as a stand-alone procedure for link-based evaluation of pedestrian service. This approach is regularly used by local, regional, and state transportation agencies. It offers the advantage of being less data-intensive than the full, 10-step methodology and produces results that are generally reflective of pedestrian perceptions of service along the roadway. It can be especially attractive when agencies are performing a networkwide evaluation for a large number of roadway links.

The analyst should recognize that the resulting link LOS does not consider some aspects of pedestrian travel along a segment (e.g., crossing difficulty or intersection service). For this reason, the LOS score for the link should not be aggregated for the purpose of characterizing facility performance. The analyst should also be aware that this approach precludes an integrated multimodal evaluation because it does not fully reflect segment performance.

Concepts

The methodology provides a variety of measures for evaluating segment performance in terms of its service to pedestrians. Each measure describes a different aspect of the pedestrian trip along the segment. One measure is the LOS score. This score is an indication of the typical pedestrian's perception of the overall segment travel experience. A second measure is the average speed of pedestrians traveling along the segment.

A third measure is based on the concept of "circulation area." It represents the average amount of sidewalk area available to each pedestrian walking along the segment. A larger area is more desirable from the pedestrian perspective. Exhibit 17-16 provides a qualitative description of pedestrian space that can be used to evaluate sidewalk performance from a circulation-area perspective.

Exhibit 17-16
Qualitative Description of Pedestrian Space

Pedestrian Space (ft²/p)		
Random Flow	Platoon Flow	Description
>60	>530	Ability to move in desired path, no need to alter movements
>40–60	>90–530	Occasional need to adjust path to avoid conflicts
>24–40	>40–90	Frequent need to adjust path to avoid conflicts
>15–24	>23–40	Speed and ability to pass slower pedestrians restricted
>8–15	>11–23	Speed restricted, very limited ability to pass slower pedestrians
≤8	≤11	Speed severely restricted, frequent contact with other users

The first two columns in Exhibit 17-16 indicate a sensitivity to flow condition. Random pedestrian flow is typical of most segments. Platoon flow is appropriate for shorter segments (e.g., in downtown areas) with signalized boundary intersections.

Step 1: Determine Free-Flow Walking Speed

The *average* free-flow pedestrian walking speed S_{pf} is needed for the evaluation of urban street segment performance from a pedestrian perspective. This speed should reflect conditions in which there are negligible pedestrian-to-pedestrian conflicts and negligible adjustments in a pedestrian's desired walking path to avoid other pedestrians.

Research indicates that walking speed is influenced by pedestrian age and sidewalk grade (*6*). If 0% to 20% of pedestrians traveling along the subject segment are elderly (i.e., 65 years of age or older), an average free-flow walking speed of 4.4 ft/s is recommended for segment evaluation. If more than 20% of pedestrians are elderly, an average free-flow walking speed of 3.3 ft/s is recommended. In addition, an upgrade of 10% or greater reduces walking speed by 0.3 ft/s.

Step 2: Determine Average Pedestrian Space

Pedestrians are sensitive to the amount of space separating them from other pedestrians and obstacles as they walk along a sidewalk. Average pedestrian space is an indicator of segment performance for travel in a sidewalk. It depends on the effective sidewalk width, pedestrian flow rate, and walking speed. This step is not applicable when the sidewalk does not exist.

A. Compute Effective Sidewalk Width

The effective sidewalk width equals the total walkway width less the effective width of fixed objects located on the sidewalk and less any shy distance associated with the adjacent street or a vertical obstruction. Fixed objects can be continuous (e.g., a fence or a building face) or discontinuous (e.g., trees, poles, or benches).

The effective sidewalk width is an average value for the length of the link. It is computed by using Equation 17-22 to Equation 17-26.

$$W_E = W_T - W_{O,i} - W_{O,o} - W_{s,i} - W_{s,o} \quad \geq 0.0$$

Equation 17-22

with

$$W_{s,i} = \max(W_{buf}, 1.5)$$

Equation 17-23

$$W_{s,o} = 3.0 p_{\text{window}} + 2.0\, p_{\text{building}} + 1.5\, p_{\text{fence}}$$

Equation 17-24

$$W_{O,i} = w_{O,i} - W_{s,i} \quad \geq 0.0$$

Equation 17-25

$$W_{O,o} = w_{O,o} - W_{s,o} \quad \geq 0.0$$

Equation 17-26

where

W_E = effective sidewalk width (ft),

W_T = total walkway width (ft),

$W_{O,i}$ = adjusted fixed-object effective width on inside of sidewalk (ft),

$W_{O,o}$ = adjusted fixed-object effective width on outside of sidewalk (ft),

$W_{s,i}$ = shy distance on inside (curb side) of sidewalk (ft),

$W_{s,o}$ = shy distance on outside of sidewalk (ft),

W_{buf} = buffer width between roadway and sidewalk (ft),

p_{window} = proportion of sidewalk length adjacent to a window display (decimal),

p_{building} = proportion of sidewalk length adjacent to a building face (decimal),

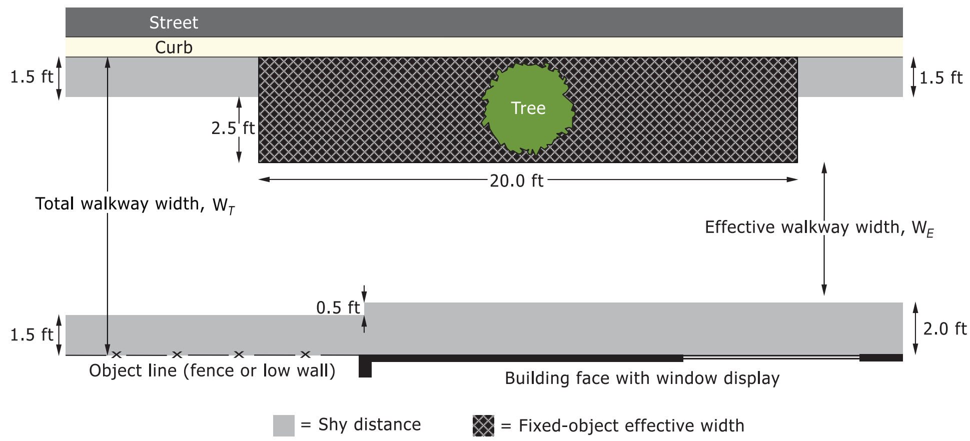
p_{fence} = proportion of sidewalk length adjacent to a fence or low wall (decimal),

$w_{O,i}$ = effective width of fixed objects on inside of sidewalk (ft), and

$w_{O,o}$ = effective width of fixed objects on outside of sidewalk (ft).

The relationship between the variables in these equations is illustrated in Exhibit 17-17.

Exhibit 17-17
Width Adjustments for Fixed Objects



The variables W_T, W_{buf}, p_{window}, p_{building}, p_{fence}, $w_{O,i}$, and $w_{O,o}$ are input variables. They represent average, or typical, values for the length of the sidewalk. Chapter 23, Off-Street Pedestrian and Bicycle Facilities, provides guidance for estimating the effective width of many common fixed objects.

Typical shy distances are shown in Exhibit 17-17. Shy distance on the inside (curb side) of the sidewalk is measured from the outside edge of the paved roadway (or face of curb, if present). It is generally considered to equal 1.5 ft. Shy distance on the outside of the sidewalk is 1.5 ft if a fence or a low wall is present, 2.0 ft if a building is present, 3.0 ft if window display is present, and 0.0 ft otherwise.

B. Compute Pedestrian Flow Rate per Unit Width

The pedestrian flow per unit width of sidewalk is computed by using Equation 17-27 for the subject sidewalk. The variable v_{ped} is an input variable.

Equation 17-27

$$v_p = \frac{v_{ped}}{60\ W_E}$$

where

- v_p = pedestrian flow per unit width (p/ft/min),
- v_{ped} = pedestrian flow rate in the subject sidewalk (walking in both directions) (p/h), and
- W_E = effective sidewalk width (ft).

C. Compute Average Walking Speed

The average walking speed S_p is computed by using Equation 17-28. This equation is derived from the relationship between flow rate and average walking speed described in Exhibit 23-1 of Chapter 23.

Equation 17-28

$$S_p = (1 - 0.00078\ v_p^2)\ S_{pf} \quad \geq 0.5\ S_{pf}$$

where S_p = pedestrian walking speed (ft/s), S_{pf} = free-flow pedestrian walking speed (ft/s), and v_p = pedestrian flow per unit width (p/ft/min).

D. Compute Pedestrian Space

Finally, Equation 17-29 is used to compute average pedestrian space.

$$A_p = 60\,\frac{S_p}{v_p}$$

Equation 17-29

where A_p is the pedestrian space (ft²/p) and other variables are as previously defined.

The pedestrian space obtained from Equation 17-29 can be compared with the ranges provided in Exhibit 17-16 to make some judgments about the performance of the subject intersection corner.

Step 3: Determine Pedestrian Delay at Intersection

Pedestrian delay at three locations along the segment is determined in this step. Each of these delays represents an input variable for the methodology and is described in Section 1, Required Input Data.

The first delay variable represents the delay incurred by pedestrians who travel through the boundary intersection along a path that is parallel to the segment centerline d_{pp}. The second delay variable represents the delay incurred by pedestrians who cross the segment at the nearest signal-controlled crossing d_{pc}. The third delay variable represents the delay incurred by pedestrians waiting for a gap to cross the segment at an uncontrolled location d_{pw}.

Step 4: Determine Pedestrian Travel Speed

Pedestrian travel speed represents an aggregate measure of speed along the segment. It combines the delay incurred at the downstream boundary intersection plus the time required to walk the length of the segment. As such, it is typically slower than the average walking speed. The pedestrian travel speed is computed by using Equation 17-30.

$$S_{Tp,seg} = \frac{L}{\frac{L}{S_p} + d_{pp}}$$

Equation 17-30

where

$S_{Tp,seg}$ = travel speed of through pedestrians for the segment (ft/s),

L = segment length (ft),

S_p = pedestrian walking speed (ft/s), and

d_{pp} = pedestrian delay when walking parallel to the segment (s/p).

In general, a travel speed of 4.0 ft/s or more is considered desirable and a speed of 2.0 ft/s or less is considered undesirable.

Step 5: Determine Pedestrian LOS Score for Intersection

The pedestrian LOS score for the boundary intersection $I_{p,int}$ is determined in this step. If the boundary intersection is signalized, then the pedestrian methodology described in Chapter 18 is used for this determination. If the boundary intersection is two-way STOP controlled, then the score is equal to 0.0.

Step 6: Determine Pedestrian LOS Score for Link

The pedestrian LOS score for the link $I_{p,link}$ is calculated by using Equation 17-31.

Equation 17-31

$$I_{p,link} = 6.0468 + F_w + F_v + F_S$$

with

Equation 17-32

$$F_w = -1.2276 \ln(W_v + 0.5\, W_1 + 50\, p_{pk} + W_{buf}\, f_b + W_{aA}\, f_{sw})$$

Equation 17-33

$$F_v = 0.0091 \frac{v_m}{4\, N_{th}}$$

Equation 17-34

$$F_s = 4\left(\frac{S_R}{100}\right)^2$$

where

$I_{p,link}$ = pedestrian LOS score for link;

F_w = cross-section adjustment factor;

F_v = motorized vehicle volume adjustment factor;

F_S = motorized vehicle speed adjustment factor;

$\ln(x)$ = natural log of x;

W_v = effective total width of outside through lane, bicycle lane, and shoulder as a function of traffic volume (see Exhibit 17-18) (ft);

W_1 = effective width of combined bicycle lane and shoulder (see Exhibit 17-18) (ft);

p_{pk} = proportion of on-street parking occupied (decimal);

W_{buf} = buffer width between roadway and available sidewalk (= 0.0 if sidewalk does not exist) (ft);

f_b = buffer area coefficient = 5.37 for any continuous barrier at least 3 ft high that is located between the sidewalk and the outside edge of roadway; otherwise use 1.0;

W_A = available sidewalk width = 0.0 if sidewalk does not exist or $W_T - W_{buf}$ if sidewalk exists (ft);

W_{aA} = adjusted available sidewalk width = min(W_A, 10) (ft);

f_{sw} = sidewalk width coefficient = 6.0 – 0.3 W_{aA};

v_m = midsegment demand flow rate (direction nearest to the subject sidewalk) (veh/h);

N_{th} = number of through lanes on the segment in the subject direction of travel (ln); and

S_R = motorized vehicle running speed = (3,600 L)/(5,280 t_R) (mi/h).

The value used for several of the variables in Equation 17-32 to Equation 17-34 is dependent on various conditions. These conditions are identified in Column 1 of Exhibit 17-18. If the condition is satisfied, then the equation in Column 2 is used to compute the variable value. If it is not satisfied, then the equation in Column 3 is used. The equations in the first two rows are considered in sequence to determine the effective width of the outside lane and shoulder W_v.

Exhibit 17-18
Variables for Pedestrian LOS Score for Link

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
p_{pk} = 0.0	$W_t = W_{ol} + W_{bl} + W_{os}^*$	$W_t = W_{ol} + W_{bl}$
v_m > 160 veh/h or street is divided	$W_v = W_t$	$W_v = W_t\,(2 - 0.005\, v_m)$
p_{pk} < 0.25 or parking is striped	$W_1 = W_{bl} + W_{os}^*$	$W_1 = 10$

Notes: W_t = total width of the outside through lane, bicycle lane, and paved shoulder (ft);
W_{ol} = width of the outside through lane (ft);
W_{os}^* = adjusted width of paved outside shoulder; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft);
W_{os} = width of paved outside shoulder (ft); and
W_{bl} = width of the bicycle lane = 0.0 if bicycle lane not provided (ft).

The buffer width coefficient determination is based on the presence of a continuous barrier in the buffer. In making this determination, repetitive vertical objects (e.g., trees or bollards) are considered to represent a continuous barrier if they are at least 3 ft high and have an average spacing of 20 ft or less. For example, the sidewalk shown in Exhibit 17-17 does not have a continuous buffer because the street trees adjacent to the curb are spaced at more than 20 ft.

The pedestrian LOS score is sensitive to the separation between pedestrians and moving vehicles; it is also sensitive to the speed and volume of these vehicles. Physical barriers and parked cars between moving vehicles and pedestrians effectively increase the separation distance and the perceived quality of service. Higher vehicle speeds or volumes lower the perceived quality of service.

If the sidewalk is not continuous for the length of the segment, then the segment should be subdivided into subsegments and each subsegment separately evaluated. For this application, a subsegment is defined to begin or end at each break in the sidewalk. Each subsegment is then separately evaluated by using Equation 17-31. Each equation variable is uniquely quantified to represent the subsegment to which it applies. The buffer width and the effective sidewalk width are each set to 0.0 ft for any subsegment without a sidewalk. The pedestrian LOS score $I_{p,link}$ is then computed as a weighted average of the subsegment scores, where the weight assigned to each score equals the portion of the segment length represented by the corresponding subsegment.

The motorized vehicle running speed is computed by using the automobile methodology, as described in a previous subsection.

Step 7: Determine Link LOS

The pedestrian LOS for the link is determined by using the pedestrian LOS score from Step 6 and the average pedestrian space from Step 2. These two performance measures are compared with their respective thresholds in Exhibit

17-3 to determine the LOS for the specified direction of travel along the subject link. If a sidewalk does not exist and pedestrians are relegated to walking in the street, then LOS is determined by using Exhibit 17-4 because the pedestrian space concept does not apply.

Step 8: Determine Roadway Crossing Difficulty Factor

The pedestrian roadway crossing difficulty factor measures the difficulty of crossing the street between boundary intersections. Segment performance from a pedestrian perspective is reduced if the crossing is perceived to be difficult.

The roadway crossing difficulty factor is based on the delay incurred by a pedestrian who crosses the subject segment. One crossing option the pedestrian may consider is to alter his or her travel path by diverting to the nearest signal-controlled crossing. This crossing location may be a midsegment signalized crosswalk or it may be a signalized intersection.

A second crossing option is to continue on the original travel path by completing a midsegment crossing at an uncontrolled location. If this type of crossing is legal along the subject segment, then the pedestrian crosses when there is an acceptable gap in the motorized vehicle stream.

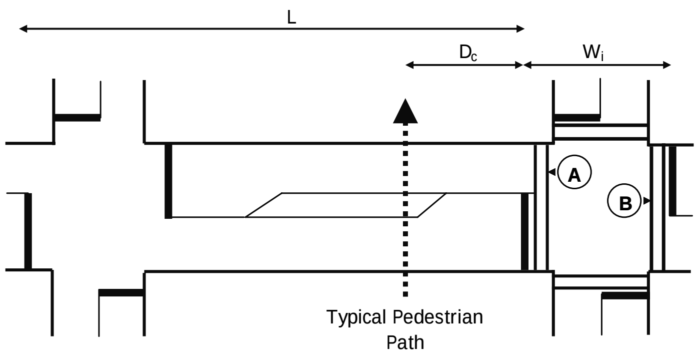
Each of these two crossing options is considered in this step, with that option requiring the least delay used as the basis for computing the pedestrian roadway crossing difficulty factor. The time to walk across the segment is common to both options and therefore is not included in the delay estimate for either option.

A. Compute Diversion Delay

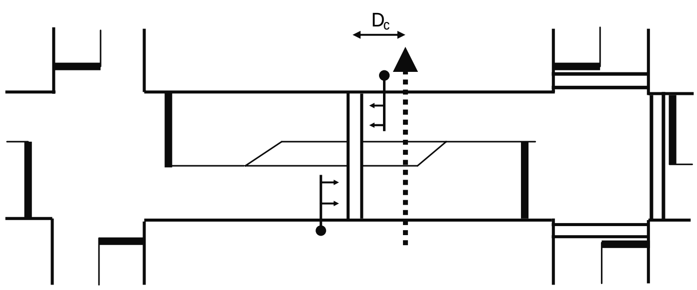
The delay incurred as a consequence of diverting to the nearest signal-controlled crossing is computed first. It includes the delay involved in walking to and from the midsegment crossing point to the nearest signal-controlled crossing and the delay waiting to cross at the signal. Hence, calculation of this delay requires knowledge of the distance to the nearest signalized crossing and its signal timing.

The distance to the nearest crossing location D_c is based on one of two approaches. The first approach is used if there is an identifiable pedestrian path (*a*) that intersects the segment and continues on beyond the segment and (*b*) on which most crossing pedestrians travel. The location of this path is shown for two cases in Exhibit 17-19. Exhibit 17-19(a) illustrates the distance D_c when the pedestrian diverts to the nearest signalized intersection. This distance is measured from the crossing location to the signalized intersection.

Exhibit 17-19
Diversion Distance Components



(a) Divert to Nearest Boundary Intersection



(b) Divert to Midsegment Signalized Crosswalk

Exhibit 17-19(b) illustrates the distance D_c when a signalized crosswalk is provided at a midsegment location. In this situation, the distance is measured from the pedestrian crossing location to the location of the signalized crosswalk. In either case, the distance D_c is an input value provided by the analyst.

The second approach is used if crossings occur somewhat uniformly along the length of the segment. In this situation the distance D_c can be assumed to equal one-third of the distance between the nearest signal-controlled crossings that bracket the subject segment.

The diversion distance to the nearest crossing is computed by using Equation 17-35.

Equation 17-35

$$D_d = 2\ D_c$$

where

D_d = diversion distance (ft), and

D_c = distance to nearest signal-controlled crossing (ft).

If the nearest crossing location is at the signalized intersection and the crossing is at Location A in Exhibit 17-19(a), then Equation 17-35 applies directly. If the nearest crossing location is at the signalized intersection but the crossing is at Location B, then the distance obtained from Equation 17-35 should be increased by adding two increments of the intersection width W_i.

The delay incurred due to diversion is calculated by using Equation 17-36.

Equation 17-36

$$d_{pd} = \frac{D_d}{S_p} + d_{pc}$$

where

d_{pd} = pedestrian diversion delay (s/p),

D_d = diversion distance (ft),

S_p = pedestrian walking speed (ft/s), and

d_{pc} = pedestrian delay when crossing the segment at the nearest signal-controlled crossing (s/p).

The pedestrian delay incurred when crossing at the nearest signal-controlled crossing was determined in Step 3.

B. Compute Roadway Crossing Difficulty Factor

The roadway crossing difficulty factor is computed by using Equation 17-37.

Equation 17-37

$$F_{cd} = 1.0 + \frac{0.10\ d_{px} - (0.318\ I_{p,link} + 0.220\ I_{p,int} + 1.606)}{7.5}$$

where

F_{cd} = roadway crossing difficulty factor,

d_{px} = crossing delay = min(d_{pd}, d_{pw}, 60) (s/p),

d_{pd} = pedestrian diversion delay (s/p),

d_{pw} = pedestrian waiting delay (s/p),

$I_{p,link}$ = pedestrian LOS score for link, and

$I_{p,int}$ = pedestrian LOS score for intersection.

If the factor obtained from Equation 17-37 is less than 0.80, then it is set equal to 0.80. If the factor is greater than 1.20, then it is set equal to 1.20.

The pedestrian waiting delay was determined in Step 3. If a midsegment crossing is illegal, then the crossing delay determination does not include consideration of the pedestrian waiting delay d_{pw} [i.e., d_{px} = min(d_{pd}, 60)].

Step 9: Determine Pedestrian LOS Score for Segment

The pedestrian LOS score for the segment is computed by using Equation 17-38.

Equation 17-38

$$I_{p,seg} = F_{cd}\left(0.318\ I_{p,link} + 0.220\ I_{p,int} + 1.606\right)$$

where $I_{p,seg}$ is the pedestrian LOS score for the segment and other variables are as previously defined.

Step 10: Determine Segment LOS

The pedestrian LOS for the segment is determined by using the pedestrian LOS score from Step 9 and the average pedestrian space from Step 2. These two performance measures are compared with their respective thresholds in Exhibit

17-3 to determine the LOS for the specified direction of travel along the subject segment. If a sidewalk does not exist and pedestrians are relegated to walking in the street, then LOS is determined by using Exhibit 17-4 because the pedestrian space concept does not apply.

BICYCLE MODE

This subsection describes the methodology for evaluating the performance of an urban street segment in terms of its service to bicyclists.

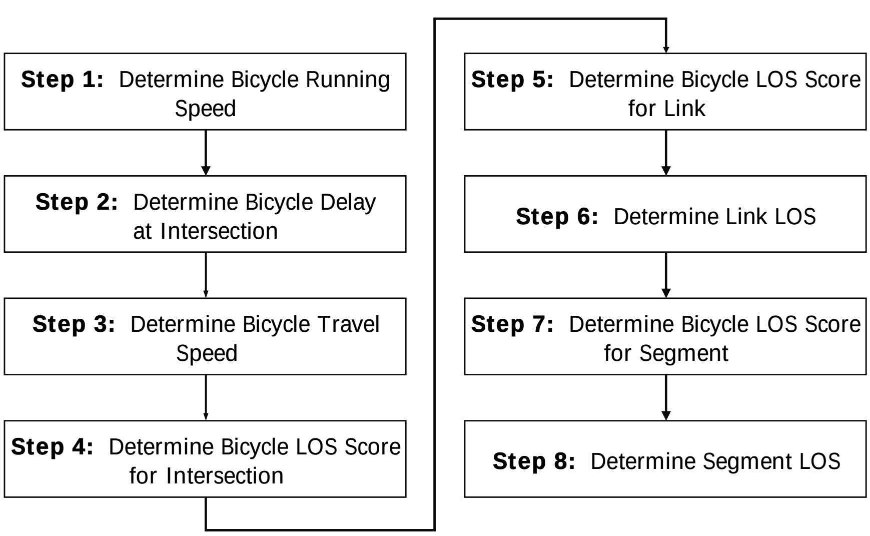
Urban street segment performance from a bicyclist perspective is separately evaluated for each travel direction along the street. *Unless otherwise stated, all variables identified in this section are specific to the subject direction of travel.* The bicycle is assumed to travel in the street (possibly in a bicycle lane) and in the same direction as adjacent motorized vehicles.

The methodology is focused on the analysis of a segment with either signal-controlled or two-way STOP-controlled boundary intersections. Chapter 18 describes a methodology for evaluating signalized intersection performance from a bicyclist perspective. No methodology exists for evaluating two-way STOP-controlled intersection performance (with the cross street STOP controlled). However, the influence of this type of control is incorporated in the methodology for evaluating segment performance. This edition of the HCM does not include a procedure for evaluating a segment's performance when the boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The bicycle methodology is applied through a series of seven steps that culminate in the determination of the segment LOS. These steps are illustrated in Exhibit 17-20. Performance measures that are estimated include bicycle travel speed and LOS scores for the link and segment.

A methodology for evaluating off-street bicycle facilities is provided in Chapter 23, Off-Street Pedestrian and Bicycle Facilities.

Exhibit 17-20
Bicycle Methodology for Urban Street Segments



Link-Based Evaluation

Steps 5 and 6 of the bicycle methodology can be used as a stand-alone procedure for link-based evaluation of bicycle service. This approach is regularly used by local, regional, and state transportation agencies. It offers the advantage of being less data-intensive than the full, eight-step methodology and produces results that are generally reflective of bicyclist perceptions of service along the roadway. It can be especially attractive when agencies are performing a networkwide evaluation for a large number of roadway links.

The analyst should recognize that the resulting link LOS does not consider some aspects of bicycle travel along a segment (e.g., intersection service). For this reason, the LOS score for the link should not be aggregated for the purpose of characterizing facility performance. The analyst should also be aware that this approach precludes an integrated multimodal evaluation because it does not fully reflect segment performance.

Step 1: Determine Bicycle Running Speed

An estimate of the *average* bicycle running speed S_b is determined in this step. The best basis for this estimate is a field measurement of midsegment bicycle speed on representative streets in the vicinity of the subject street. In the absence of this information, it is recommended that the average running speed of bicycles be taken as 15 mi/h between signalized intersections (*7*). It is recognized that many factors might affect bicycle speed, including adjacent motor vehicle traffic, adjacent on-street parking activity, commercial and residential driveways, lateral obstructions, and significant grades. To date, research is not available to make any specific recommendations as to the effect of these factors on speed.

Step 2: Determine Bicycle Delay at Intersection

Bicycle delay at the boundary intersection d_b is computed in this step. This delay is incurred by bicyclists who travel through the intersection in the same lane as (or in a bicycle lane that is parallel to the lanes used by) segment through vehicles.

If the boundary intersection is two-way STOP controlled (where the subject approach is uncontrolled), then the delay is equal to 0.0 s/bicycle. If the boundary intersection is signalized, then the delay is computed by using the methodology described in Chapter 18, Signalized Intersections.

Step 3: Determine Bicycle Travel Speed

Bicycle travel speed represents an aggregate measure of speed along the segment. It combines the delay incurred at the downstream boundary intersection and the time required to ride the length of the segment. As such, it is typically slower than the average bicycle running speed. The average bicycle travel speed is computed by using Equation 17-39.

Equation 17-39

$$S_{Tb,seg} = \frac{3{,}600\ L}{5{,}280\ (t_{Rb} + d_b)}$$

where

$S_{Tb,seg}$ = travel speed of through bicycles along the segment (mi/h),

L = segment length (ft),

t_{Rb} = segment running time of through bicycles = (3,600 L)/(5,280 S_b) (s),

S_b = bicycle running speed (mi/h), and

d_b = bicycle control delay (s/bicycle).

In general, a travel speed of 10.0 mi/h or more is considered desirable and a speed of 5.0 mi/h or less is considered undesirable.

Step 4: Determine Bicycle LOS Score for Intersection

The bicycle LOS score for the boundary intersection $I_{b,int}$ is determined in this step. If the boundary intersection is signalized, then the bicycle methodology described in Chapter 18 is used for this determination. If the boundary intersection is two-way STOP controlled, then the score is equal to 0.0.

Step 5: Determine Bicycle LOS Score for Link

The bicycle LOS score for the segment $I_{b,link}$ is calculated by using Equation 17-40.

$$I_{b,link} = 0.760 + F_w + F_v + F_S + F_p$$

Equation 17-40

with

$$F_w = -0.005\ W_e^2$$

Equation 17-41

$$F_v = 0.507 \ln\left(\frac{v_{ma}}{4\ N_{th}}\right)$$

Equation 17-42

$$F_S = 0.199\ \left[1.1199 \ln(S_{Ra} - 20) + 0.8103\right]\left(1 + 0.1038\ P_{HVa}\right)^2$$

Equation 17-43

$$F_p = \frac{7.066}{P_c^{\ 2}}$$

Equation 17-44

where

$I_{b,link}$ = bicycle LOS score for link,

F_w = cross-section adjustment factor,

F_v = motorized vehicle volume adjustment factor,

F_S = motorized vehicle speed adjustment factor,

F_p = pavement condition adjustment factor,

$\ln(x)$ = natural log of x,

W_e = effective width of outside through lane (see Exhibit 17-21) (ft),

v_{ma} = adjusted midsegment demand flow rate (see Exhibit 17-21) (veh/h),

N_{th} = number of through lanes on the segment in the subject direction of travel (ln),

S_{Ra} = adjusted motorized vehicle running speed (see Exhibit 17-21) (mi/h),

P_{HVa} = adjusted percent heavy vehicles in midsegment demand flow rate (see Exhibit 17-21) (%), and

P_c = pavement condition rating (see Exhibit 17-7).

The value used for several of the variables in Equation 17-41 to Equation 17-44 is dependent on various conditions. These conditions are identified in Column 1 of Exhibit 17-21. If the condition is satisfied, then the equation in Column 2 is used to compute the variable value. If it is not satisfied, then the equation in Column 3 is used. The equations in the first three rows are considered in sequence to determine the effective width of the outside through lane W_e.

The motorized vehicle running speed is computed by using the automobile methodology described in a previous subsection.

Step 6: Determine Link LOS

The bicycle LOS for the link is determined by using the bicycle LOS score from Step 5. This performance measure is compared with the thresholds in Exhibit 17-4 to determine the LOS for the specified direction of travel along the subject link.

Exhibit 17-21
Variables for Bicycle LOS Score for Link

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
p_{pk} = 0.0	$W_t = W_{ol} + W_{bl} + W_{os}^*$	$W_t = W_{ol} + W_{bl}$
v_m > 160 veh/h or street is divided	$W_v = W_t$	$W_v = W_t\,(2 - 0.005\ v_m)$
$W_{bl} + W_{os}^* < 4.0$ ft	$W_e = W_v - 10\ p_{pk} \geq 0.0$	$W_e = W_v + W_{bl} + W_{os}^* - 20\ p_{pk} \geq 0.0$
$v_m\,(1\text{-}\ 0.01\ P_{HV}) < 200$ veh/h and P_{HV} > 50%	P_{HVa} = 50%	$P_{HVa} = P_{HV}$
S_R < 21 mi/h	S_{Ra} = 21 mi/h	$S_{Ra} = S_R$
$v_m > 4\ N_{th}$	$v_{ma} = v_m$	$v_{ma} = 4\ N_{th}$

Notes:
W_t = total width of the outside through lane, bicycle lane, and paved shoulder (ft);
W_{ol} = width of outside through lane (ft);
W_{os}^* = adjusted width of paved outside shoulder; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft);
W_{os} = width of paved outside shoulder (ft);
W_{bl} = width of bicycle lane = 0.0 if bicycle lane not provided (ft);
W_v = effective total width of outside through lane, bicycle lane, and shoulder as a function of traffic volume (ft);
p_{pk} = proportion of on-street parking occupied (decimal);
v_m = midsegment demand flow rate (veh/h);
P_{HV} = percent heavy vehicles in the midsegment demand flow rate (%), and
S_R = motorized vehicle running speed (mi/h).

Step 7: Determine Bicycle LOS Score for Segment

The bicycle LOS score for the segment is computed by using Equation 17-45.

Equation 17-45

$$I_{b,seg} = 0.160\ I_{b,link} + 0.011\ F_{bi}\ e^{I_{b,int}} + 0.035\ \frac{N_{ap,s}}{(L/5280)} + 2.85$$

where

$I_{b,seg}$ = bicycle LOS score for segment;

$I_{b,link}$ = bicycle LOS score for link;

F_{bi} = indicator variable for boundary intersection control type = 1.0 if signalized, 0.0 if two-way STOP controlled;

$I_{b,int}$ = bicycle LOS score for intersection; and

$N_{ap,s}$ = number of access point approaches on the right side in the subject direction of travel (points).

The count of access point approaches used in Equation 17-45 includes both public street approaches and driveways on the right side of the segment in the subject direction of travel.

Step 8: Determine Segment LOS

The bicycle LOS for the segment is determined by using the segment bicycle LOS score from Step 7. This performance measure is compared with the thresholds in Exhibit 17-4 to determine the LOS for the specified direction of travel along the subject segment.

TRANSIT MODE

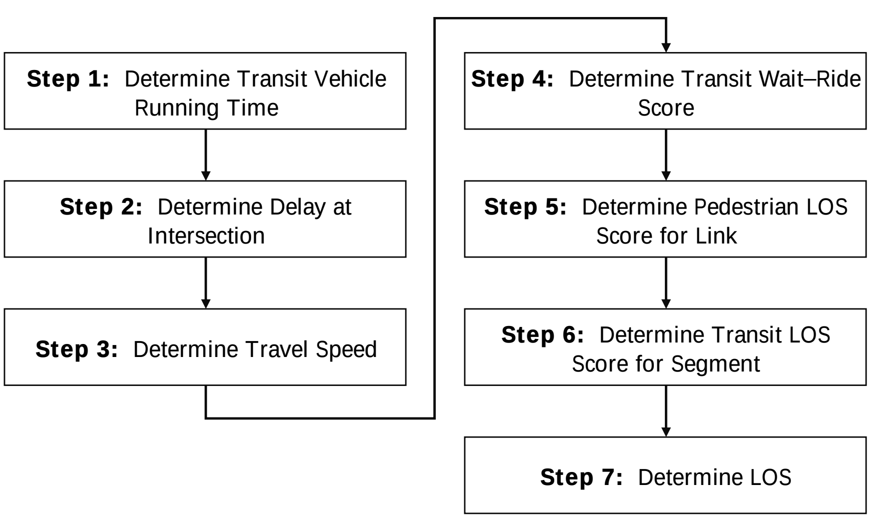
This subsection describes the methodology for evaluating the performance of an urban street segment in terms of its service to transit passengers.

Urban street segment performance from a transit-passenger perspective is separately evaluated for each travel direction along the street. *Unless otherwise stated, all variables identified in this section are specific to the subject direction of travel.*

The methodology is applicable to public transit vehicles operating in mixed traffic or exclusive lanes and stopping along the street. Procedures for estimating transit vehicle performance on grade-separated or non-public-street rights-of-way, along with procedures for estimating origin–destination service quality, are provided in the *Transit Capacity and Quality of Service Manual* (*3*).

The transit methodology is applied through a series of six steps that culminate in the determination of segment LOS. These steps are illustrated in Exhibit 17-22. Performance measures that are estimated include transit travel speed along the street, transit wait–ride score, and a LOS score reflective of all transit service stopping within or near the segment.

Exhibit 17-22
Transit Methodology for Urban Street Segments



Step 1: Determine Transit Vehicle Running Time

There are two principal components of the transit vehicle's segment running time. One component represents the time required to travel the segment without stopping. (To allow direct comparison with automobile segment speeds, transit vehicles are treated as if they travel the entire segment, even if they join midlink.) The second component is the delay incurred at the transit stops that are provided on the link. The following subparts to this step describe procedures that are used to calculate these components. They culminate with a subpart that describes the calculation of transit vehicle segment running time.

A. Compute Segment Running Speed

Transit vehicle segment running speed represents the speed reached by the vehicle when not influenced by the proximity of a transit stop or traffic control device. This speed can be computed by using Equation 17-46, which is derived from tables given in a Transit Cooperative Research Program report (*8*).

Equation 17-46

$$S_{Rt} = \min\left(S_R , \frac{61}{1 + e^{-1.00 + (1{,}185\, N_{ts} / L)}} \right)$$

where

S_{Rt} = transit vehicle running speed (mi/h),

L = segment length (ft),

N_{ts} = number of transit stops on the segment for the subject route (stops),

S_R = motorized vehicle running speed = (3,600 L)/(5,280 t_R) (mi/h), and

t_R = segment running time (s).

The segment running time is computed by using Equation 17-6 in Step 2 of the automobile methodology.

B. Compute Delay due to a Stop

The delay due to a transit vehicle stop for passenger pickup includes the following components:

- Acceleration–deceleration delay,
- Delay due to serving passengers, and
- Reentry delay.

This procedure is applied once for each stop on the segment. The delay due to each stop is added (in a subsequent step) to compute the total delay due to all stops on the segment.

Acceleration–Deceleration Delay

Acceleration–deceleration delay represents the additional time required to decelerate to stop and then accelerate back to the transit vehicle running speed S_{Rt}. It is computed by using Equation 17-47 and Equation 17-48.

Equation 17-47

$$d_{ad} = \frac{5{,}280}{3{,}600}\left(\frac{S_{Rt}}{2} \right)\left(\frac{1}{r_{at}} + \frac{1}{r_{dt}} \right) f_{ad}$$

with

$$f_{ad} = \begin{cases} 1.00 & \text{(stops not on the near side of a boundary intersection)} \\ 0.00 & \text{(near-side stops at all-way and major-street two-way STOP-controlled intersections)} \\ 1-x & \text{(near-side stops at roundabouts)} \\ g/C & \text{(near-side stops at traffic signals)} \end{cases}$$

Equation 17-48

where

d_{ad} = transit vehicle acceleration–deceleration delay due to a transit stop (s),

r_{at} = transit vehicle acceleration rate = 4.0 (ft/s^2),

r_{dt} = transit vehicle deceleration rate = 4.0 (ft/s^2),

f_{ad} = proportion of transit vehicle stop acceleration–deceleration delay not due to traffic control,

x = volume-to-capacity ratio of the link's rightmost lane on a roundabout approach,

g = effective green time (s), and

C = cycle length (s).

Acceleration–deceleration delay represents travel time that is in excess of that required to traverse the equivalent distance at the running speed. It is incurred when the transit vehicle stops solely because of a transit stop. When a transit stop is located on the near side of a boundary intersection, a transit vehicle might need to stop anyway due to the traffic control. In this situation, acceleration–deceleration delay is already included in the through delay estimate (addressed in a subsequent step) and should not be included in d_{ad}. Equation 17-48 is used to determine the proportion of d_{ad} incurred solely because of a transit stop.

If representative acceleration and deceleration rates are known, then they should be used in Equation 17-47. If these rates are unknown, then a rate of 4.0 ft/s^2 may be assumed for both acceleration and deceleration (*8*).

Delay due to Serving Passengers

The delay due to serving passengers is based on the average dwell time, which is an input to this procedure. At signalized intersections, a portion of the dwell time may overlap time the transit vehicle would have spent stopped anyway due to the traffic control. Equation 17-49 is used to compute the delay due to serving passengers.

$$d_{ps} = t_d f_{dt}$$

Equation 17-49

where

d_{ps} = transit vehicle delay due to serving passengers (s),

t_d = average dwell time (s), and

f_{dt} = proportion of dwell time occurring during effective green (= g/C at near-side stops at signalized intersections and 1.00 otherwise, where g and C are as previously defined).

Reentry Delay

The final component of transit vehicle stop delay is the reentry delay d_{re}, which is an input to this procedure. Guidance for estimating reentry delay is provided in the Required Input Data subsection of Section 1, Introduction.

Delay due to a Stop

Delay due to a transit stop is the sum of acceleration–deceleration delay, passenger service time delay, and reentry delay. It is computed by using Equation 17-50.

Equation 17-50

$$d_{ts} = d_{ad} + d_{ps} + d_{re}$$

where d_{ts} = delay due to a transit vehicle stop (s), d_{re} = reentry delay (s), and other variables are as previously defined.

C. Compute Segment Running Time

Equation 17-51 is used to compute transit vehicle running time, which is based on segment running speed and delay due to stops on the segment.

Equation 17-51

$$t_{Rt} = \frac{3{,}600\ L}{5{,}280\ S_{Rt}} + \sum_{i=1}^{N_{ts}} d_{ts,i}$$

where t_{Rt} = segment running time of transit vehicle (s), $d_{ts,i}$ = delay due to a transit vehicle stop for passenger pickup at stop i within the segment (s), and other variables are as previously defined.

If there are no stops on the segment, then the second term of Equation 17-51 equals zero.

Step 2: Determine Delay at Intersection

The through delay incurred at the boundary intersection is determined in this step. This delay is that incurred by the through movement that exits the segment at the downstream boundary intersection. Guidance for determining this delay is provided in Step 5 of the automobile methodology. Equation 17-52 can be used for a planning analysis to estimate the through delay due to a traffic signal (*8*).

Equation 17-52

$$d_t = t_l\ 60 \left(\frac{L}{5{,}280} \right)$$

where

d_t = through delay (s/veh),

t_l = transit vehicle running time loss (min/mi), and

L = segment length (ft).

The running time loss t_l used in Equation 17-52 is obtained from Exhibit 17-23.

Exhibit 17-23
Transit Vehicle Running Time Loss

Area Type	Transit Lane Allocation	Traffic Condition	Running Time Loss by Signal Condition (min/mi): Typical	Signals Set for Transit	Signals More Frequent Than Transit Stops
Central business district	Exclusive	No right turns	1.2	0.6	1.5–2.0
		With right-turn delay	2.0	1.4	2.5–3.0
		Blocked by traffic	2.5–3.0	Not available	3.0–3.5
	Mixed traffic	Any	3.0	Not available	3.5–4.0
Other	Exclusive	Any	0.7 (0.5–1.0)	Not available	Not available
	Mixed traffic	Any	1.0 (0.7–1.5)	Not available	Not available

Source: St. Jacques and Levinson (*8*).

Step 3: Determine Travel Speed

Transit travel speed represents an aggregate measure of speed along the street. It combines the delay incurred at the downstream intersection with the segment running time. As such, it is typically slower than the running speed. The transit travel speed is computed by using Equation 17-53.

Equation 17-53

$$S_{Tt,seg} = \frac{3{,}600\ L}{5{,}280\ (t_{Rt} + d_t)}$$

where $S_{Tt,seg}$ = travel speed of transit vehicles along the segment (mi/h), t_{Rt} = segment running time of transit vehicle (s), and other variables are as previously defined.

Step 4: Determine Transit Wait–Ride Score

The transit wait–ride score is a performance measure that combines perceived time spent waiting for the transit vehicle and perceived travel time rate. If transit service is not provided for the subject direction of travel, then this score equals 0.0 and the analysis continues with Step 5.

The procedure for calculating the wait–ride score is described in this step. It consists of the separate calculation of the headway factor and the perceived travel time factor. The following subparts describe these two calculations, which culminate in the calculation of the wait–ride score.

A. Compute Headway Factor

The headway factor is the ratio of the estimated patronage at the prevailing average transit headway to the estimated patronage at a base headway of 60 min. The patronage values for the two headways (i.e., the input headway and the base headway of 60 min) are computed from an assumed set of patronage elasticities that relate the percentage change in ridership to the percentage change in headway. The headway factor is computed by using Equation 17-54.

Equation 17-54

$$F_h = 4.00\ e^{-1.434/(v_s + 0.001)}$$

where

F_h = headway factor, and

v_s = transit frequency for the segment (veh/h).

The transit frequency v_s is an input to this procedure. Guidance for estimating this input is provided in the Required Input Data subsection.

B. Compute Perceived Travel Time Factor

Segment performance, as measured by the wait–ride score, is influenced by the travel time rate provided to transit passengers. The perceptibility of this rate is further influenced by the extent to which the transit vehicle is late, crowded, or both and whether the stop provides passenger amenities. In general, travel at a high rate is preferred, but travel at a lower rate may be nearly as acceptable if the transit vehicle is not late, the bus is lightly loaded, and a shelter (with a bench) is provided at the transit stop.

The perceived travel time factor is based on the perceived travel time rate and the expected ridership elasticity with respect to changes in the perceived travel time rate. This factor is computed by using Equation 17-55.

Equation 17-55

$$F_{tt} = \frac{(e-1)\ T_{btt} - (e+1)\ T_{ptt}}{(e-1)\ T_{ptt} - (e+1)\ T_{btt}}$$

with

Equation 17-56

$$T_{ptt} = \left(a_1\ \frac{60}{S_{Tt,seg}}\right) + \left(2\ T_{ex}\right) - T_{at}$$

Equation 17-57

$$a_1 = \begin{cases} 1.00 & F_l \le 0.80 \\ 1 + \dfrac{(4)(F_l - 0.80)}{4.2} & 0.80 < F_l \le 1.00 \\ 1 + \dfrac{(4)(F_l - 0.80) + (F_l - 1.00)(6.5 + [(5)(F_l - 1.00)])}{4.2 \times F_l} & F_l > 1.00 \end{cases}$$

Equation 17-58

$$T_{at} = \frac{1.3\ p_{sh} + 0.2\ p_{be}}{L_{pt}}$$

where

F_{tt} = perceived travel time factor;

e = ridership elasticity with respect to changes in the travel time rate = -0.40;

T_{btt} = base travel time rate = 6.0 for the central business district of a metropolitan area with 5 million persons or more, otherwise = 4.0 (min/mi);

T_{ptt} = perceived travel time rate (min/mi);

T_{ex} = excess wait time rate due to late arrivals (min/mi) = t_{ex}/L_{pt};

t_{ex} = excess wait time due to late arrivals (min);

T_{at} = amenity time rate (min/mi);

a_1 = passenger load weighting factor;

$S_{Tt,seg}$ = travel speed of transit vehicles along the segment (mi/h);

F_l = average passenger load factor (passengers/seat);

L_{pt} = average passenger trip length = 3.7 typical (mi);

p_{sh} = proportion of stops on segment with shelters (decimal); and

p_{be} = proportion of stops on segment with benches (decimal).

The perceived travel time rate is estimated according to three components, as shown in Equation 17-56. The first component reflects the average travel speed of the transit service, adjusted for the degree of passenger loading. The second component reflects the average excess wait time for the transit vehicle (i.e., the amount of time spent waiting for a late arrival beyond the scheduled arrival time). The third component reflects the ability of passengers to tolerate longer travel time rates when there are amenities provided at the transit stops.

The first term in Equation 17-56 includes a factor that adjusts the transit vehicle travel time rate by using a passenger load weighting factor. This factor accounts for the decrease in passenger comfort when transit vehicles are crowded. Values of this factor range from 1.00 when the passenger load factor is less than 0.80 passengers/seat to 2.32 when the load factor is 1.6 passengers/seat.

The second term in Equation 17-56 represents the perceived excess wait time rate. It is based on the excess wait time t_{ex} associated with late transit arrivals. The multiplier of 2 in Equation 17-56 is used to amplify the excess wait time rate because passengers perceive excess waiting time to be more onerous than actual travel time.

The excess wait time t_{ex} reflects transit vehicle reliability. It is an input to this procedure. If excess wait time data are not available for a stop, but on-time performance data are available for routes using the stop, then Equation 17-59 may be used to estimate the average excess wait time.

Equation 17-59

$$t_{ex} = [t_{late}(1 - p_{ot})]^2$$

where

t_{ex} = excess wait time due to late arrivals (min),

t_{late} = threshold late time = 5.0 typical (min), and

p_{ot} = proportion of transit vehicles arriving within the threshold late time (default = 0.75) (decimal).

The third term in Equation 17-56 represents the amenity time rate reduction. This rate is computed in Equation 17-58 as the equivalent time value of various transit stop improvements divided by the average passenger trip length. If multiple transit stops exist on the segment, an average amenity time rate should be used for the segment, based on the average value for all stops in the segment.

The average passenger trip length is used to convert time values for excess wait time and amenities into distance-weighted travel time rates that adjust the perceived in-vehicle travel time rate. The shorter the trip, the greater the influence that late transit vehicles and stop amenities have on the overall perceived speed of the trip.

The average passenger trip length should be representative of transit routes using the subject segment. A value of 3.7 mi is considered to be nationally representative. More accurate local values can be obtained from the National Transit Database (*4*). Specifically, this database provides annual passenger miles and annual unlinked trips in the profile of most transit agencies. The average passenger trip length is computed as the annual passenger miles divided by the annual unlinked trips.

C. Compute Wait–Ride Score

The wait–ride score is computed by using Equation 17-60. A larger score corresponds to better performance.

Equation 17-60

$$s_{w-r} = F_h \; F_{tt}$$

where

s_{w-r} = transit wait–ride score,

F_h = headway factor, and

F_{tt} = perceived travel time factor.

Step 5: Determine Pedestrian LOS Score for Link

The pedestrian LOS score for the link $I_{p,link}$ is computed by using the pedestrian methodology, as described in a previous subsection.

Step 6: Determine Transit LOS Score for Segment

The transit LOS score for the segment is computed by using Equation 17-61.

Equation 17-61

$$I_{t,seg} = 6.0 - 1.50 \; s_{w-r} + 0.15 \; I_{p,link}$$

where $I_{t,seg}$ is the transit LOS score for the segment and other variables are as defined previously.

Step 7: Determine LOS

The transit LOS is determined by using the transit LOS score from Step 6. This performance measure is compared with the thresholds in Exhibit 17-4 to determine the LOS for the specified direction of travel along the subject street segment.

3. APPLICATIONS

DEFAULT VALUES

Agencies that use the methodologies in this chapter are encouraged to develop a set of local default values based on field measurements on streets in their jurisdiction. Local default values provide the best means of ensuring accuracy in the analysis results. In the absence of local default values, the values identified in this subsection can be used if the analyst believes that they are reasonable for the street segment to which they are applied.

Exhibit 17-5 and Exhibit 17-6 identify the input data variables associated with the automobile, pedestrian, bicycle, and transit methodologies. These variables can be categorized as either (*a*) suitable for specification as a default value or (*b*) required input data. Those variables categorized as "suitable for specification as a default value" have a minor effect on performance estimates and tend to have a relatively narrow range of typical values used in practice. In contrast, required input variables have either a notable effect on performance estimates or a wide range of possible values. Variables suitable for default value specification are discussed in this subsection.

Required input variables typically represent fundamental segment and intersection geometric elements and demand flow rates. Values for these variables should be field measured whenever possible.

If field measurement of the input variables is not possible, then various options exist for determining an appropriate value for a required input variable. As a first choice, input values should be established through the use of local guidelines. If local guidelines do not address the desired variable, then some input values may be determined by considering the typical operation of (or conditions at) similar segments and intersections in the jurisdiction. As a last option, various authoritative national guideline documents are available and should be used to make informed decisions about design options and volume estimates. The use of simple rules of thumb or "ballpark" estimates for required input values is discouraged because this use is likely to lead to a significant cumulative error in the performance estimates.

Automobile Mode

The required input variables for the automobile methodology are identified in the following list. These variables represent the minimum basic input data that the analyst will need to provide for an analysis. These variables were previously defined in the text associated with Exhibit 17-5.

- Demand flow rate (at boundary intersection),
- Capacity (at boundary intersection),
- Number of lanes (at boundary intersection),
- Upstream intersection width (at boundary intersection),
- Turn bay length (at boundary intersection),
- Number of through lanes,

- Segment length,
- Restrictive median length (if present),
- Speed limit,
- Through control delay (at boundary intersection),
- Through stopped vehicles (at boundary intersection), and
- Second- and third-term back of queue (at boundary intersection).

Several authoritative reference documents (*9–11*) provide useful guidelines for selecting the type of signal control at the boundary intersection and determining the appropriate traffic control for the segment.

Exhibit 17-24 lists default values for the automobile methodology. Some of the values listed may also be useful for the pedestrian, bicycle, or transit methodologies. The last column of this exhibit indicates "see discussion" for one variable. In this situation, the default value is described in the discussion provided in this subsection.

Exhibit 17-24
Default Values: Automobile Mode

Data Category	Input Data Element	Default Values
Traffic characteristics	Access point flow rate	See discussion
	Midsegment flow rate	Estimate by using demand flow rate at the downstream boundary intersection approach
Geometric design	Number of lanes at access points	Segment Approach If median is present, one left-turn lane/approach. If no median is present, no left-turn lanes. No right-turn lanes. Through lanes are the same as N_{th}. Access Point Approach One left-turn lane and one right-turn lane.
	Turn bay length at access points	40% of the access point spacing, where spacing equals 2 (5,280) / D_{ap} in feet. Computed bay length should not exceed 300 ft or be less than 50 ft.
	Proportion of segment with curb	1.0 (curb present on both sides of segment)
	Number of access point approaches	Estimated for each segment side by multiplying default access point density by 1/2 segment length (i.e., $N_{ap,s}$ = 0.5 D_{ap} L / 5,280) Urban arterial D_{ap} = 34 points/mi Suburban arterial D_{ap} = 21 points/mi Urban collector D_{ap} = 61 points/mi Suburban collector D_{ap} = 48 points/mi
Other	Analysis period duration	0.25 h
Performance measures	Midsegment delay	0.0 s/veh
	Midsegment stops	0.0 stops/veh

Note: D_a = access point density on segment (points/mi); $N_{ap,s}$ =number of access point approaches on the right side in the subject direction of travel (points); L = segment length (ft); and N_{th} = number of through lanes on the segment in the subject direction of travel (ln).

The default access point flow rate can be estimated from the midsegment flow rate by using default turn proportions. These proportions are shown in Exhibit 17-25 for a typical access point intersection on an arterial street. The proportion of 0.05 for the left-turn movements can be reduced to 0.01 for a typical access point on a collector street. These proportions are appropriate for segments with an access point density consistent with the default densities in Exhibit 17-24 and are applicable to access points serving any public-oriented land use (this excludes single-family residential land use and undeveloped property).

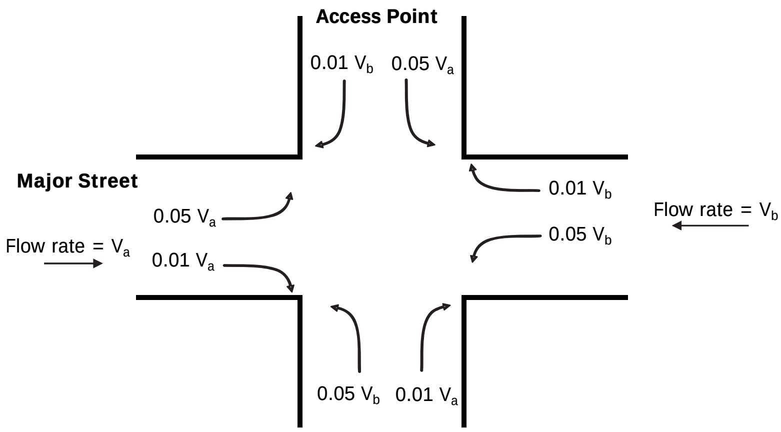


Exhibit 17-25
Default Turn Proportions for Access Point Intersections

If one of the movements shown in Exhibit 17-25 does not exist at a particular access point intersection, then its volume is not computed (its omission has no effect on the proportion used for the other movement flow rates). The flow rate for the crossing movements at an access point intersection is not needed for the automobile methodology. The left-turn proportions shown are larger than the right-turn proportions because right-turn opportunities are typically more frequent than left-turn opportunities along an arterial street.

Nonautomobile Modes

The required input variables for the pedestrian, bicycle, and transit methodologies are identified in the list below. These variables represent the minimum basic input data that the analyst will need to provide for an analysis. These variables were previously defined in the text associated with Exhibit 17-6.

<u>Pedestrian Methodology</u>

- Midsegment flow rate
- Pedestrian flow rate
- Downstream intersection width (at boundary intersection)
- Segment length
- Number of through lanes
- Median type and curb presence
- Spacing of objects in buffer
- Legality of midsegment pedestrian crossing
- Proportion of segment adjacent to window display
- Proportion of segment adjacent to building face
- Proportion of segment adjacent to low wall or fence
- Motorized vehicle running speed
- Pedestrian delay

- Pedestrian LOS score for intersection

<u>Bicycle Methodology</u>

- Midsegment flow rate
- Segment length
- Number of through lanes
- Median type and curb presence
- Motorized vehicle running speed
- Bicycle delay (at boundary intersection)
- Bicycle LOS score for intersection

<u>Transit Methodology</u>

- Excess wait time (or on-time performance)
- Transit frequency
- Segment length
- Area type
- Transit stop location
- Transit stop position
- Proportion of stops with shelters
- Proportion of stops with benches
- Motorized vehicle running speed
- Pedestrian LOS score for link
- Through control delay (at boundary intersection)
- Reentry delay
- Effective green-to-cycle-length ratio (at boundary intersection)
- Volume-to-capacity ratio (at roundabout boundary intersection)

Exhibit 17-26 lists the default values for the pedestrian, bicycle, and transit methodologies (*2, 12*).

TYPES OF ANALYSIS

The automobile, pedestrian, bicycle, and transit methodologies described in this chapter can each be used in three types (or levels) of analysis. These analysis levels are described as operational, design, and planning and preliminary engineering. The characteristics of each analysis level are described in the subsequent parts of this subsection.

Operational Analysis

Each of the methodologies is most easily applied at an operational level of analysis. At this level, all traffic, geometric, and signalization conditions are specified as input variables by the analyst. These input variables are used in the methodology to compute various performance measures.

Exhibit 17-26
Default Values: Nonautomobile Modes

Data Category	Input Data Element	Default Value
Traffic characteristics	Dwell time	Downtown stop, transit center, major on-line transfer point, major park-and-ride stop: 60 s Major outlying stop: 30 s Typical outlying stop: 15 s
	Passenger trip length	3.7 mi
	Passenger load factor	0.80 passengers/seat
	Percent heavy vehicles	3%
	Proportion of on-street parking occupied	0.50 (if parking lane present)
Geometric design	Width of outside through lane	12 ft
	Width of bicycle lane	5.0 ft (if provided)
	Width of paved outside shoulder	No parking lane: 1.5 ft (curb and gutter width) Parking lane present: 8.0 ft
	Number of access point approaches	Estimated for each segment side by multiplying default access point density by segment length (i.e., $N_{ap,s}$ = 0.5 D_{ap} L / 5,280) Urban arterial D_{ap} = 34 points/mi Suburban arterial D_{ap} = 21 points/mi Urban collector D_{ap} = 61 points/mi Suburban collector D_{ap} = 48 points/mi
	Total walkway width	Business or office land use: 9.0 ft Residential or industrial land use: 11.0 ft
	Effective width of fixed objects	Business or office land use: 2.0 ft inside, 2.0 ft outside Residential or industrial land use: 0.0 ft inside, 0.0 ft outside
	Buffer width	Business or office land use: 0.0 ft Residential or industrial land use: 6.0 ft
Other	Pavement condition rating	3.5
	Distance to nearest signal-controlled crossing	One-third the distance between signal-controlled crossings that bracket the segment
Performance measures	Delay at midsegment signalized crosswalk	20 s/p

Note: D_a = access point density on segment (points/mi); $N_{ap,s}$ =number of access point approaches on the right side in the subject direction of travel (points); L = segment length (ft); and N_{th} = number of through lanes on the segment in the subject direction of travel (ln).

Design Analysis

The nature of the design analysis varies depending on whether the boundary intersections are unsignalized or signalized. When the segment has unsignalized boundary intersections, the analyst specifies traffic conditions and target levels for a specified set of performance measures. The methodology is then applied by using an iterative approach in which alternative geometric conditions are separately evaluated.

When the segment has signalized boundary intersections, the design level of analysis has two variations. Both variations require the specification of traffic conditions and target levels for a specified set of performance measures. One variation requires the additional specification of the signalization conditions. The methodology is then applied by using an iterative approach in which alternative geometric conditions are separately evaluated.

The second variation of the design level requires the additional specification of the geometric conditions. The methodology is then applied by using an iterative approach in which alternative signalization conditions are evaluated.

The objective of the design analysis is to identify the alternatives that operate at the target level of the specified performance measures (or provide a better level of performance). The analyst may then recommend the "best" design alternative after consideration of the full range of factors.

Planning and Preliminary Engineering Analysis

The planning and preliminary engineering level of analysis is intended to provide an estimate of the LOS for either a proposed segment or an existing segment in a future year. This level of analysis may also be used to size the overall geometrics of a proposed segment.

The level of precision inherent in planning and preliminary engineering analyses is typically lower than for operational analyses. Therefore, default values are often substituted for field-measured values of many of the input variables. Recommended default values for this purpose were described previously in this section.

The requirement for a complete description of the signal timing plan can be a burden for some planning analyses involving signalized intersections, especially when the signal control is pretimed or coordinated–actuated. The intersection Quick Estimation Method described in Chapter 31, Signalized Intersections: Supplemental, can be used to estimate a reasonable timing plan, in conjunction with the aforementioned default values.

For some planning and preliminary engineering analyses, the segment Quick Estimation Method described in Chapter 30, Urban Street Segments: Supplemental, may provide a better balance between accuracy and analysis effort in the evaluation of vehicle LOS.

USE OF ALTERNATIVE TOOLS

General guidance for the use of alternative traffic analysis tools for capacity and LOS analysis is provided in Chapter 6, HCM and Alternative Analysis Tools, and Chapter 7, Interpreting HCM and Alternative Tool Results. This section contains specific guidance for the application of alternative tools to the analysis of urban street segments. The tools are described as either simulation or deterministic, in reference to their traffic modeling approach. Additional information on this topic is provided in Volume 4. The focus of this section is the application of alternative tools to evaluate automobile operation.

Strengths of the Automobile Methodology

The automobile methodology described in Section 2 models the driver–vehicle–road system with reasonable accuracy for most applications. It accounts for midsegment speed variations due to traffic and geometric conditions. Alternative tools offer a more detailed treatment of the arrival and departure of vehicles as well as the interaction between the vehicle, the roadway, and the control system. As such, some tools can model the driver–vehicle–road system more accurately for some applications.

The automobile methodology offers several advantages over alternative analysis tools. One advantage is that it has an empirically calibrated procedure for estimating saturation flow rate. Alternative tools often require saturation flow rate as an input variable. A second advantage is that it produces a direct estimate of capacity and volume-to-capacity ratio. These measures are not directly available from simulation tools. A third advantage is that it produces an expected value for each of a wide variety of data outputs in a single application. Many alternative tools operate as a "black box," providing little detail describing the intermediate calculations. Moreover, simulation tools require multiple runs and manual calculations to obtain expected values for the output data.

Identified Limitations of the Automobile Methodology

The limitations of the automobile methodology are identified in Section 1. If any of these limitations apply to a particular situation, then alternative tools may produce more credible performance estimates. Limitations involving consideration of the impact of progression on performance are a special case that is discussed in more detail in Chapter 16, Urban Street Facilities.

Features and Performance Measures Available from Alternative Tools

Both deterministic tools and simulation tools are in common use as alternatives to the procedures offered in this chapter. Deterministic tools are used to a greater extent for the analysis of urban street segments than for most of the other transportation elements represented in this manual. The main reasons for their popularity are found in the user interface, optimization options, and output presentation features. Some also offer additional performance measures such as fuel consumption, air quality, and operating cost.

Development of HCM-Compatible Performance Measures Using Alternative Tools

The LOS assessment for the automobile mode on urban street segments is based on the average travel speed over the segment. The average travel speed is computed by dividing the segment length by the total time required to travel the segment, taking into account all intersection and nonintersection delays.

Alternative tools generally define the travel speed in the same way that it is defined in this chapter. However, these tools may not compute delay and running speed by using the procedures presented in Section 2. Therefore, some care must be taken when using speed and delay estimates from other tools. Issues related to speed and delay comparison among different tools are discussed in more detail in Chapter 7. In general, the travel speed from an alternative tool should not be used for LOS assessment unless the tool is confirmed to apply the procedures described in Section 2.

Conceptual Differences That Preclude Direct Comparison of Results

Alternative deterministic tools apply traffic models that are conceptually similar to those described in this chapter. While their computational details will usually produce different numerical results, there are few major conceptual differences that would preclude comparison in terms of relative magnitude.

Simulation tools, on the other hand, are based on entirely different modeling concepts. A general discussion of the conceptual differences is presented in Chapters 6 and 7. Some specific examples for signalized intersections, which also apply to urban street segments, are presented in Chapter 18.

One phenomenon that makes comparison difficult is the propagation of platoons along a segment. Deterministic tools, including the model presented in this chapter, apply equations that spread out a platoon as it progresses downstream. Simulation tools create platoon dispersion implicitly from a distribution of desired speeds among drivers. Both approaches will produce platoon dispersion, but the amount of dispersion will differ among tools.

Simulation tools may also exhibit platoon compression because of the effect of slower-moving vehicles that cause platoons to regenerate. For this and other reasons, it is difficult to achieve comparability of platoon representation along a segment between these tools and the automobile methodology.

Adjustment of Alternative Tool Parameters

For applications in which either an alternative tool or the automobile methodology can be used, some adjustment will generally be required for the alternative tool if some consistency with the automobile methodology is desired. For example, the parameters that determine the capacity of a signalized approach (e.g., saturation flow rate and start-up lost time) should be adjusted to ensure that the lane group (or approach) capacities match those estimated by the automobile methodology.

It might also be necessary to adjust the parameters that affect the travel time along the segment to produce comparable results. The automobile methodology is based on a free-flow speed that is computed as a function of demand flow rate, median type, access point density, and speed limit. Most alternative tools typically require a user-specified free-flow speed, which could be obtained from the automobile methodology to maintain comparability. It may be more difficult to adjust the platoon modeling parameters. So, if comparability is desired in representing the platoon effect, it is preferable to adjust the free-flow speed specified for simulation such that the actual travel speeds are similar to those obtained from the automobile methodology.

Step-by-Step Recommendations for Applying Alternative Tools

A set of step-by-step recommendations for signalized intersection evaluation with alternative tools is presented in Chapter 18. The recommendations in that chapter also apply to the evaluation of urban street segments.

Sample Calculations Illustrating Alternative Tool Applications

The most useful examples of the application of alternative tools involve multiple segment facilities. Chapter 29, Urban Street Facilities: Supplemental, includes a set of examples to illustrate the use of alternative tools to address the stated limitations of this chapter and Chapter 16, Urban Street Facilities.

Specifically, these examples illustrate (*a*) the application of deterministic tools to optimize signal timing, (*b*) the effect of using a roundabout as a segment boundary, (*c*) the effect of midsegment parking maneuvers on facility operation, and (*d*) the use of simulated vehicle trajectories to evaluate the proportion of time that the back of the queue on the minor-street approach to a two-way STOP-controlled intersection exceeds a specified distance from the stop line.

Chapter 31, Signalized Intersections: Supplemental, includes example problems that address left-turn storage bay overflow, right-turn-on-red operation, short through lanes, and closely spaced intersections.

4. EXAMPLE PROBLEMS

This part of the chapter describes the application of each of the automobile, pedestrian, bicycle, and transit methodologies through the use of example problems. Exhibit 17-27 provides an overview of these problems. The focus of the examples is on the operational analysis level. The planning and preliminary engineering analysis level is identical to the operational analysis level in terms of the calculations, except that default values are used when field-measured values are not available.

Exhibit 17-27
Example Problems

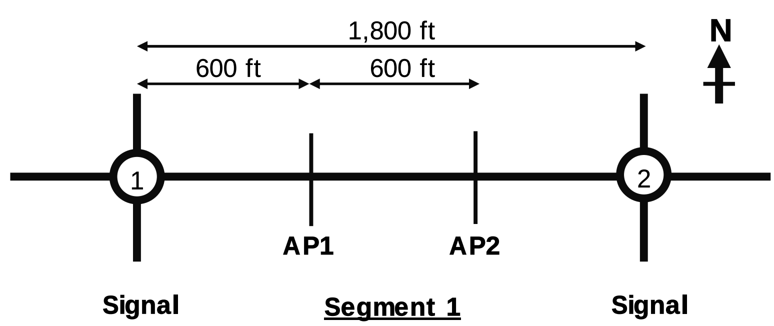
Problem Number	Description	Analysis Level
1	Automobile LOS	Operational
2	Pedestrian LOS	Operational
3	Bicycle LOS	Operational
4	Transit LOS	Operational

EXAMPLE PROBLEM 1: AUTOMOBILE LOS

The Urban Street Segment

The total length of an undivided urban street segment is 1,800 ft. It is shown in Exhibit 17-28. 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 17-28
Example Problem 1: Urban Street Segment Schematic



The segment has two access point intersections, shown in the exhibit as AP1 and AP2. 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." So, the few vehicles that do turn at these locations during the analysis period have been added to the appropriate flow rates at the two access point intersections.

The Question

What are the travel speed, spatial stop rate, and LOS during the analysis period for the segment through movement in both directions of travel?

The Facts

The segment's traffic counts are listed in Exhibit 17-29. The counts were taken during the 15-min analysis period of interest. However, they have been converted to hourly flow rates. It is noted that the volumes leaving the signalized intersections do not add to equal the volume arriving at the downstream access point intersection.

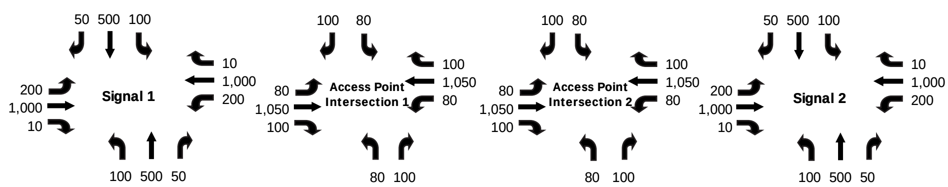


Exhibit 17-29
Example Problem 1: Intersection Turn Movement Counts

The signalization conditions are shown in Exhibit 17-30. The conditions shown are identified as belonging to Signalized Intersection 1; however, they are the same for Signalized Intersection 2. The signals operate with coordinated–actuated control. The left-turn movements on the northbound and southbound approaches operate under protected–permitted control and lead the opposing through movements (i.e., a lead–lead phase sequence). The left-turn movements on the major street operate as protected-only in a lead–lead sequence.

Exhibit 17-30
Example Problem 1: Signal Conditions for Intersection 1

Signalized Intersection 1								
General Information								
Cross Street:	First Avenue				**Analysis Period:**	7:15 am to 7:30 am		
Phase Sequence and Left-Turn Mode								
Major street sequence (movement numbers shown)	5 & 1 left leading				Cross street sequence (movement numbers shown)	3 & 7 left leading		
Major street left-turn mode (movement numbers shown)	5/1 Protected-Only				Cross street left-turn mode (movement numbers shown)	3/7 Protected+Permitted		
Phase Settings								
Approach	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Phase number	5	2	1	6	3	8	7	4
Movement	L	T+R	L	T+R	L	T+R	L	T+R
Lead/lag left-turn phase	Lead	--	Lead	--	Lead	--	Lead	--
Left-turn mode	Prot.	--	Prot.	--	Pr/Pm	--	Pr/Pm	--
Passage time, s	2.0	--	2.0	--	2.0	2.0	2.0	2.0
Minimum green, s	5	--	5	--	5	5	5	5
Yellow + red clear, s	3.0	4.0	3.0	4.0	3.0	4.0	3.0	4.0
Phase split, s	20	35	20	35	20	25	20	25
Recall	No	--	No	--	No	No	No	No
Dual entry	No	Yes	No	Yes	No	Yes	No	Yes
Ref. Phase: 2	Offset, s:	0	Offset Ref.:	End of Green		Force Mode:	Fixed	
	Cycle, s:	100						
Enable Simultaneous Gap-Out? Phase Group 1,2,5,6: ☑ Phase Group 3,4,7,8: ☑					Enable Dallas Left-Turn Phasing? Phases 1,2,5,6: ☐ Phases 3,4,7,8: ☐			

Exhibit 17-30 indicates that the passage time for each phase is 2.0 s. The minimum green setting is 5 s for each phase. The offset to Phase 2 (the reference phase) end-of-green interval is 0.0 s. A fixed-force mode is used to ensure that coordination is maintained. The cycle length is 100 s.

Geometric conditions and traffic characteristics for Signalized Intersection 1 are shown in Exhibit 17-31. They are the same for Signalized Intersection 2. The movement numbers follow the numbering convention shown in Exhibit 18-2 of Chapter 18.

Exhibit 17-31
Example Problem 1: Geometric Conditions and Traffic Characteristics for Signalized Intersection 1

Signalized Intersection 1												
Signalized Intersection Input Data *(In each column, enter the volume and lanes data. For all other blue cells, enter values only if there is one or more lanes.)*												
Approach	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Movement number	5	2	12	1	6	16	3	8	18	7	4	14
Volume, veh/h	200	1,000	10	200	1,000	10	100	500	50	100	500	50
Lanes	1	2	1	1	2	1	1	2	0	1	2	0
Turn bay length, ft	200		200	200		200	200			200		
Sat. flow rate, veh/h/ln	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800		1,800	1,800	
Platoon ratio	1.000	1.333	1.000	1.000	1.333	1.000	1.000	1.000		1.000	1.000	
Initial queue, veh	0	0	0	0	0	0	0	0		0	0	
Speed limit, mph	35	35	35	35	35	35	35	35	35	35	35	35
Stop line det. length, ft	40			40			40	40		40	40	
Max. allow. hdwy, s/veh	3.9			3.9			3.9	2.9		3.9	2.9	

All signalized intersection approaches have a 200-ft left-turn bay and two through lanes. The east–west approaches have a 200-ft right-turn lane. The north–south approaches have a shared through and right-turn lane. The saturation flow rate is determined by using the procedure described in Chapter 18.

The platoon ratio is entered for all movements associated with an external approach to the segment. The eastbound through movement at Signalized Intersection 1 is coordinated with the upstream intersection such that favorable progression occurs, as described by a platoon ratio of 1.33. The westbound through movement at Signalized Intersection 2 is also coordinated with its upstream intersection, and arrivals are described by a platoon ratio of 1.33. Arrivals to all other movements are characterized as "random" and are described with a platoon ratio of 1.00. The movements for the westbound approach at Signalized Intersection 1 (and eastbound approach at Signalized Intersection 2) are internal movements, so the input platoon ratios shown will only be used for the first iteration of calculations. More accurate values are computed during subsequent iterations by using a procedure provided in the methodology.

The speed limit on the segment and on the cross-street approaches is 35 mi/h. A 40-ft detection zone is located just upstream of the stop line in each traffic lane at the two signalized intersections.

The geometric conditions that describe the segment are shown in Exhibit 17-32. These data are used to compute the free-flow speed for the segment.

The traffic and lane assignment data for the two access point intersections are shown in Exhibit 17-33. The movement numbers follow the numbering convention shown in Exhibit 19-3 of Chapter 19, Two-Way STOP-Controlled Intersections. There are no turn bays on the segment at the two access point intersections.

Exhibit 17-32
Example Problem 1: Segment Data

Segment 1		
Free-Flow Speed Computation		
Input Data		
	EB	**WB**
Basic Segment Data		
Number of through lanes that extend the length of the segment:	2	2
Speed limit, mph	35	35
Segment Length Data		
Length of segment (measured stopline to stopline), ft	1,800	1,800
Width of upstream signalized intersection, ft	50	50
Adjusted segment length, ft	1,750	1,750
Length of segment with a restrictive median (e.g, raised-curb), ft	0	0
Length of segment with a non-restrictive median (e.g, two-way left-turn lane), ft	0	0
Length of segment with no median, ft	1,750	1,750
Percentage of segment length with restrictive median, %	0	0
Access Data		
Percentage of street with curb on right-hand side (in direction of travel), %	70	70
Number of access points on right-hand side of street (in direction of travel)	4	4
Access point density, access points/mi	24	24

Exhibit 17-33
Example Problem 1: Access Point Data

Access Point Input Data													
Access Point Location,ft	Approach	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
	Movement	L	T	R	L	T	R	L	T	R	L	T	R
	Movement number	1	2	3	4	5	6	7	8	9	10	11	12
600	Volume, veh/h	80	1,050	100	80	1,050	100	80	0	100	80	0	100
West end	Lanes	0	2	0	0	2	0	1	0	1	1	0	1
1200	Volume, veh/h	80	1,050	100	80	1,050	100	80	0	100	80	0	100
	Lanes	0	2	0	0	2	0	1	0	1	1	0	1

Outline of Solution

Movement-Based Data

Exhibit 17-34 provides a summary of the analysis of the individual traffic movements at Signalized Intersection 1.

Exhibit 17-34
Example Problem 1: Movement-Based Output Data

INTERSECTION 1	**EB**	**EB**	**EB**	**WB**	**WB**	**WB**	**NB**	**NB**	**NB**	**SB**	**SB**	**SB**
	L	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Movement:	**5**	**2**	**12**	**1**	**6**	**16**	**3**	**8**	**18**	**7**	**4**	**14**
Volume, veh/h	200	1,000	10	194	968	10	100	500	50	100	500	50
Lanes	1	2	1	1	2	1	1	2	0	1	2	0
Bay Length, ft	200	0	200	200	0	200	200	0	0	200	0	0
Saturation Flow Rate, veh/h/ln	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Platoon Ratio	1.00	1.33	1.00	1.00	1.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Initial Queue, veh	0	0	0	0	0	0	0	0	0	0	0	0
Speed Limit, mph	35	35	35	35	35	35	35	35	35	35	35	35
Detector Length, ft	40	0	0	40	0	0	40	40	40	40	40	40
Capacity, veh/h	234	1,703	724	230	1,695	720	213	609	61	213	609	61
Discharge Volume, veh/h	0	1,000	0	0	0	0	0	0	50	100	0	0
Proportion Arriving On Green	0.137	0.630	0.473	0.046	0.456	0.460	0.063	0.189	0.189	0.063	0.189	0.189
Approach Volume, veh/h		1,210			1,172			650			650	
Approach Delay, s/veh		19.4			25.5			39.4			39.4	
Approach Stop Rate, stops/veh		0.471			0.668			0.850			0.850	

With one exception, the first eight rows of data in Exhibit 17-34 are an "echo" of the input data. The remaining rows list variables that are computed by using these input data. The volumes shown in Exhibit 17-34 for the eastbound (EB), northbound (NB), and southbound (SB) movements are identical to the input volumes. The westbound (WB) volumes were reduced from the input volumes during Step 1: Determine Traffic Demand Adjustments. This reduction occurred because the westbound volume input for this intersection exceeded the volume departing the upstream access point intersection (i.e., AP1).

Capacity for a movement is computed by using the movement volume proportion in each approach lane group, lane group saturation flow rate, and corresponding phase duration. This variable represents the capacity of the movement, regardless of whether it is served in an exclusive lane or a shared lane. If the movement is served in a shared lane, then the movement capacity represents the portion of the lane group capacity available to the movement, as distributed in proportion to the flow rate of the movements served by the associated lane group.

Discharge volume is computed for those movements that enter a segment during Step 1: Determine Traffic Demand Adjustments. At Signalized Intersection 1, the movements entering the segment are the eastbound through movement, northbound right-turn movement, and southbound left-turn movement. A value of 0.0 veh/h is shown for all other movements and indicates that they are not relevant to this calculation. If volume exceeds capacity for any given movement, then the discharge volume is set equal to the capacity. Otherwise, the discharge volume is equal to the movement volume.

The proportion arriving during green *P* is computed for internal movements during Step 3: Determine the Proportion Arriving During Green. In contrast, it is computed from the input platoon ratio for external movements.

The last three rows in Exhibit 17-34 represent summary statistics for the approach. The approach volume represents the sum of the three movement volumes. Approach delay and approach stop rate are computed as volume-weighted averages for the lane groups served on an intersection approach.

Timer-Based Phase Data

Exhibit 17-35 provides a summary of the output data for Signalized Intersection 1 using a signal controller perspective. The controller has eight timing functions (or timers), with Timers 1 to 4 representing Ring 1 and Timers 5 to 8 representing Ring 2. The ring structure and phase assignments are described in Chapter 18. Timers 1, 2, 5, and 6 are used to control the east–west traffic movements on the segment. Timers 3, 4, 7, and 8 are used to control the north–south movements that cross the segment.

Exhibit 17-35
Example Problem 1: Timer-Based Phase Output Data

Timer Data

Timer:	**1 WB L**	**2 EB T.R**	**3 NB L**	**4 SB T.T+R**	**5 EB L**	**6 WB T.R**	**7 SB L**	**8 NB T.T+R**
Assigned Phase	1	2	3	4	5	6	7	8
Case No	2	3	1	4	2	3	1	4
Phase Duration (G+Y+Rc), s	16.48	51.29	9.32	22.90	16.69	51.09	9.32	22.90
Change Period (Y+Rc), s	3.00	4.00	3.00	4.00	3.00	4.00	3.00	4.00
Phase Start Time, s	36.22	52.70	4.00	13.32	36.22	52.92	4.00	13.32
Phase End Time, s	52.70	4.00	13.32	36.22	52.92	4.00	13.32	36.22
Max. Allowable Headway (MAH), s	3.13	0.00	3.13	3.06	3.13	0.00	3.13	3.06
Equivalent Maximum Green (Gmax), s	29.78	0.00	17.00	31.68	29.78	0.00	17.00	31.68
Max. Queue Clearance Time (g_c+I1),	13.238	0.000	6.644	16.955	13.432	0.000	6.644	16.955
Green Extension Time (g_e), s	0.302	0.000	0.098	1.946	0.313	0.000	0.098	1.946
Probability of Phase Call (p_c)	0.995	0.000	0.938	1.000	0.996	0.000	0.938	1.000
Probability of Max Out (p_x)	0.000	0.000	0.000	0.023	0.000	0.000	0.000	0.023

Cycle Length, s: 100

The timing function construct is essential to the modeling of a ring-based signal controller. *Timers* always occur in the same numeric sequence (i.e., 1 then 2 then 3 then 4 in Ring 1; 5 then 6 then 7 then 8 in Ring 2). The practice of associating movements with phases (e.g., the major-street through movement to Phase 2), coupled with the occasional need for lagging left-turn phases and split phasing, creates the situation in which *phases* do not always time in sequence. For example, with a lagging left-turn phase sequence, major-street through Phase 2 times first and then major-street left-turn Phase 1 times second.

The modern controller accommodates the assignment of phases to timing functions by allowing the ring structure to be redefined manually or by time-ofday settings. Specification of this structure is automated in the computational engine by the assignment of phases to timers.

The methodology is based on modeling *timers*, not by directly modeling movements or phases. The methodology converts movement and phase input data into timer input data. It then models controller response to these inputs and computes timer duration and related performance measures.

The two signalized intersections in this example problem have lead–lead left-turn sequences. Hence, the timer number is equal to the phase number (e.g., the westbound movement is associated with Phase 1, which is assigned to Timer 1).

The case number shown in Exhibit 17-35 is used as a single variable descriptor of each possible combination of left-turn mode and lane group type (i.e., shared or exclusive). An understanding of this variable is not needed to interpret the output data.

The phase duration shown in Exhibit 17-35 represents the estimated average phase duration during the analysis period. It represents the sum of the green, yellow change, and red clearance intervals. For Timer 2 (i.e., Phase 2), the average green interval duration can be computed as 47.29 s (= 51.29 – 4.00).

The phase start time represents the time the timer (and phase) starts, relative to system time 0.0. For Phase 2, the start time is 52.70 s. The end of the green interval associated with this phase is 100.0 s (= 52.70 + 47.29). This time is equal to the cycle length, so the end of green actually occurs at 0.0 s. This result is expected because Phase 2 is the coordinated phase and the offset to the end of Phase 2 (relative to system time 0.0) was input as 0.0 s.

The phase end time represents the time the timer (and phase) ends relative to system time 0.0. For Phase 2, the end of the green interval occurs at 0.0 s and the end of the phase occurs 4.0 s later (i.e., the change period duration).

The remaining variables in Exhibit 17-35 apply to the noncoordinated phases (i.e., the actuated phases). These variables describe the phase timing and operation. They are described in more detail in Chapter 18.

Timer-Based Movement Data

Exhibit 17-36 summarizes the output for Signalized Intersection 1 as it relates to the movements assigned to each timer. Separate sections of output are shown in the exhibit for the left-turn, through, and right-turn movements. The assigned movement row identifies the movement (previously identified in Exhibit 17-34) assigned to each timer.

The saturation flow rate shown in Exhibit 17-36 represents the saturation flow rate for the movement. The procedure for calculating these rates is described in Chapter 18. In general, the rate for a movement is the same as for a lane group when the lane group serves one movement. The rate is split between the movements when the lane group is shared by two or more movements.

Exhibit 17-36
Example Problem 1: Timer-Based Movement Output Data

Timer Data								
Timer:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	WB	**EB**	**NB**	**SB**	**EB**	**WB**	**SB**	**NB**
	L	**T.R**	**L**	**T.T+R**	**L**	**T.R**	**L**	**T.T+R**
Left-Turn Movement Data								
Assigned Movement	1		3		5		7	
Mvmt. Sat Flow, veh/h	1,710.00		1,710.00		1,710.00		1,710.00	
Through Movement Data								
Assigned Movement		2		4		6		8
Mvmt. Sat Flow, veh/h		3,600.00		3,222.18		3,600.00		3,222.18
Right-Turn Movement Data								
Assigned Movement		12		14		16		18
Mvmt. Sat Flow, veh/h		1,530.00		321.15		1,530.00		321.15

Timer-Based Lane Group Data

The methodology described in Chapter 18 computes a variety of output data that describe the operation of each intersection lane group. The example problem in Chapter 18 illustrates these data and discusses their interpretation. The output data for the individual lane groups are not repeated in this chapter. Instead, the focus of the remaining discussion is on the access point output and the performance measures computed for the two segment through movements.

Access Point Data

Exhibit 17-37 illustrates the output statistics for the two access point intersections located on the segment. The first six rows listed in the exhibit correspond to Access Point Intersection 1 (AP1), and the second six rows correspond to Access Point Intersection 2 (AP2). Additional sets of six rows would be provided in this table if additional access point intersections were evaluated.

Exhibit 17-37
Example Problem 1: Movement-Based Access Point Output Data

Access Point Data	**EB**	**EB**	**EB**	**WB**	**WB**	**WB**	**NB**	**NB**	**NB**	**SB**	**SB**	**SB**
Segment 1	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Movement:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Access Point Intersection No. 1												
1: Volume, veh/h	74.80	981.71	93.50	75.56	991.70	94.45	80.00	0.00	100.00	80.00	0.00	100.00
1: Lanes	0	2	0	0	2	0	1	0	1	1	0	1
1: Proportion time blocked	0.170			0.170			0.260	0.260	0.170	0.260	0.260	0.170
1: Delay to through vehicles, s/veh		0.163			0.164							
1: Prob. inside lane blocked by left		0.101			0.101							
1: Dist. from West/South signal, ft	600											
Access Point Intersection No. 2												
2: Volume, veh/h	75.56	991.70	94.45	74.80	981.71	93.50	80.00	0.00	100.00	80.00	0.00	100.00
2: Lanes	0	2	0	0	2	0	1	0	1	1	0	1
2: Proportion time blocked	0.170			0.170			0.260	0.260	0.170	0.260	0.260	0.170
2: Delay to through vehicles, s/veh		0.164			0.163							
2: Prob. inside lane blocked by left		0.101			0.101							
2: Dist. from West/South signal, ft	1,200											

The eastbound and westbound volumes listed in Exhibit 17-37 are not equal to the input volumes. These volumes were adjusted during Step 1: Determine Traffic Demand Adjustments such that they equal the volume discharging from the upstream intersection. This routine achieves balance between all junction pairs (e.g., between Signalized Intersection 1 and Access Point Intersection 1, between Access Point Intersection 1 and Access Point Intersection 2, and so forth).

The proportion of time blocked is computed during Step 3: Determine the Proportion Arriving During Green. It represents the proportion of time during the cycle that the associated access point movement is blocked by the presence of a platoon passing through the intersection. For major-street left turns, the platoon of concern approaches from the opposing direction. For the minor-street left turn, platoons can approach from either direction and can combine to block this left turn for extended time periods. This trend can be seen by comparing the proportion of time blocked for the eastbound (major-street) left turn (i.e., 0.17) with that for the northbound (minor-street) left turn (i.e., 0.26) at Access Point Intersection 1.

The delay to through vehicles is computed during Step 2: Determine Running Time. It represents the sum of the delay due to vehicles turning left from the major street and the delay due to vehicles turning right from the major street. This delay tends to be small compared with typical signalized intersection delay values. But it can influence travel speed if there are several high-volume access points on a street and only one or two through lanes in each direction of travel.

The probability of the inside through lane being blocked is also computed during Step 2: Determine Running Time as part of the delay-to-through-vehicles procedure. This variable indicates the probability that the left-turn bay at an access point will overflow into the inside through lane on the street segment. Hence, it indicates the potential for a through vehicle to be delayed by a left-turn maneuver. The segment being evaluated has an undivided cross section, and no left-turn bays are provided at the access point intersections. In this situation, the probability of overflow is 0.10, indicating that the inside lane is blocked about 10% of the time.

Results

Exhibit 17-38 summarizes the performance measures for the segment. Also shown are the results from the spillback check conducted during Step 1: Determine Traffic Demand Adjustments. The movements indicated in the column heading represent the movements exiting the segment at a boundary intersection. Thus, the westbound movements on Segment 1 are those that occur at Signalized Intersection 1. Similarly, the eastbound movements on Segment 1 are those that occur at Signalized Intersection 2.

Exhibit 17-38
Example Problem 1: Performance Measure Summary

Segment Summary		EB	EB	EB	WB	WB	WB
		L	T	R	L	T	R
Seg.No.	Movement:	5	2	12	1	6	16
1	Bay/Lane Spillback Time, h	never	never	never	never	never	never
1	ShrdLane Spillback Time, h	never	never	never	never	never	never
1	Base Free-Flow Speed, mph		40.78			40.78	
1	Running Time, s		33.48			33.48	
1	Running Speed, mph		36.65			36.65	
1	Through Delay, s/veh		20.862			20.862	
1	Travel Speed, mph		22.58			22.58	
1	Stop Rate, stops/veh		0.608			0.608	
1	Spatial Stop Rate, stops/mi		1.78			1.78	
1	Through vol/cap ratio		0.57			0.57	
1	Percent of Base FFS		55.4			55.4	
1	Level of Service		C			C	
1	Proportion Left Lanes		0.33			0.33	
1	Auto. Traveler Perception Score		2.56			2.56	
SPILLBACK TIME, h: never							

The spillback check procedure computes the time of spillback for each of the internal movements. For turn movements, the bay/lane spillback time represents the time before the turn bay overflows. For through movements, the bay/lane spillback time represents the time before the through lane overflows due only to through demand. If a turn bay exists and it overflows, then the turn volume will queue in the adjacent through lane. For this scenario, the shared lane spillback time is computed and used instead of the bay/lane spillback time. If several movements experience spillback, then the time of first spillback is reported at the bottom of Exhibit 17-38.

The output data for the two through movements are listed in Exhibit 17-38, starting with the third row. The base free-flow speed (FFS) and running time statistics are computed during Step 2: Determine Running Time. The through delay listed is computed during Step 5: Determine Through Control Delay. It represents a weighted average delay for the lane groups serving through movements at the downstream boundary intersection. The weight used in this average is the volume of through vehicles served by the lane group.

The percent of base free-flow speed equals the travel speed divided by the base free-flow speed. It and the through movement volume-to-capacity ratio are used with Exhibit 17-2 to determine that the segment is operating at LOS C in both travel directions.

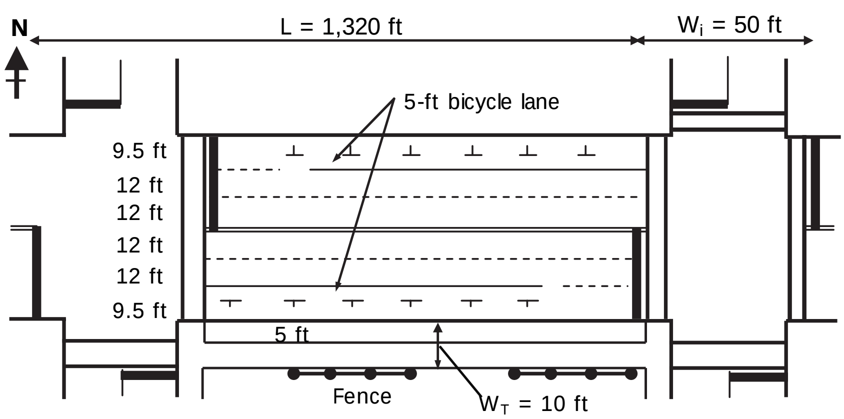
Each travel direction has one left-turn bay and three intersections. Thus, the proportion of intersections with left-turn lanes is 0.33. This proportion is used in Step 10: Determine Automobile Traveler Perception Score to compute the score of 2.56, which suggests that most automobile travelers would find segment service to be very good.

EXAMPLE PROBLEM 2: PEDESTRIAN LOS

The Segment

The sidewalk of interest is located along a 1,320-ft urban street segment. The segment is part of a collector street located near a community college. It is shown in Exhibit 17-39. Sidewalk is only shown for the south side of the segment for the convenience of illustration. It also exists on the north side of the segment.

Exhibit 17-39
Example Problem 2: Segment Geometry



The Question

What is the pedestrian LOS for the sidewalk on the south side of the segment?

The Facts

The geometric details of the sidewalk and street cross section are shown in Exhibit 17-39. Both boundary intersections are signalized. It is legal to cross the segment at uncontrolled, midsegment locations. The following additional information is known about the sidewalk and street segment:

<u>Traffic Characteristics</u>

Midsegment flow rate in eastbound direction: 940 veh/h

Pedestrian flow rate in south sidewalk (walking in both directions): 2,000 p/h

Proportion of on-street parking occupied during analysis period: 0.20

<u>Geometric Characteristics</u>

Shoulder width consists of 8.0 ft for parking and 1.5 ft for gutter pan.

Cross section has raised curb along outside edge of roadway.

Effective width of fixed objects on sidewalk: 0.0 ft (no objects present)

Presence of trees, bushes, or other vertical objects in buffer: No

<u>Other Data</u>

Pedestrians can cross the segment legally and do so somewhat uniformly along its length.

Proportion of sidewalk adjacent to window display: 0.0

Proportion of sidewalk adjacent to building face: 0.0

Proportion of sidewalk adjacent to fence: 0.50

<u>Performance Measures Obtained from Supporting Methodologies</u>

Motorized vehicle running speed: 33 mi/h

Pedestrian delay when walking parallel to the segment: 40 s/p

Pedestrian delay when crossing the segment at the nearest signal-controlled crossing: 80 s/p

Pedestrian waiting delay: 740 s/p

Pedestrian LOS score for the downstream intersection: 3.6

Outline of Solution

First, the pedestrian space will be calculated for the sidewalk. This measure will then be compared with the qualitative descriptions of pedestrian space listed in Exhibit 17-16. Next, the pedestrian travel speed along the sidewalk will be calculated. Finally, LOS for the crossing will be determined by using the computed pedestrian LOS score and pedestrian space variables with Exhibit 17-3.

Computational Steps

Step 1: Determine Free-Flow Walking Speed

The average free-flow walking speed is estimated to be 4.4 ft/s on the basis of the guidance provided.

Step 2: Determine Average Pedestrian Space

The shy distance on the inside of the sidewalk is computed by using Equation 17-23.

$$W_{s,i} = \max(W_{buf}, 1.5)$$

$$W_{s,i} = \max(5.0, 1.5)$$

$$W_{s,i} = 5.0 \text{ ft}$$

The shy distance on the outside of the sidewalk is computed by using Equation 17-24.

$$W_{s,o} = 3.0 P_{\text{window}} + 2.0\, P_{\text{building}} + 1.5\, P_{\text{fence}}$$

$$W_{s,o} = 3.0(0.0) + 2.0\,(0.0) + 1.5\,(0.50)$$

$$W_{s,o} = 0.75 \text{ ft}$$

There are no fixed objects present on the sidewalk, so the adjusted fixed-object effective widths for the inside and outside of the sidewalk are both equal to 0.0 ft. The effective sidewalk width is computed by using Equation 17-22.

$$W_E = W_T - W_{O,i} - W_{O,o} - W_{s,i} - W_{s,o} \quad \geq 0.0$$

$$W_E = 10 - 0.0 - 0.0 - 5.0 - 0.75$$

$$W_E = 4.25 \text{ ft}$$

The pedestrian flow per unit width of sidewalk is computed by using Equation 17-27 for the subject sidewalk.

$$v_p = \frac{v_{ped}}{60\, W_E}$$

$$v_p = \frac{2{,}000}{60\,(4.25)}$$

$$v_p = 7.84 \text{ p/ft/min}$$

The average walking speed S_p is computed by using Equation 17-28.

$$S_p = (1 - 0.00078\, v_p^2)\, S_{pf} \quad \geq 0.5\, S_{pf}$$

$$S_p = (1 - 0.00078\, [7.84]^2)\; 4.4$$

$$S_p = 4.19 \text{ ft/s}$$

Finally, Equation 17-29 is used to compute average pedestrian space.

$$A_p = 60\, \frac{S_p}{v_p}$$

$$A_p = 60\, \frac{4.19}{7.84}$$

$$A_p = 32.0 \text{ ft}^2\text{/p}$$

The pedestrian space can be compared with the ranges provided in Exhibit 17-16 to make some judgments about the performance of the subject intersection corner. The criteria for platoon flow are considered applicable given the influence of the signalized intersections. According to the qualitative descriptions provided in this exhibit, walking speed will be restricted as will the ability to pass slower pedestrians.

Step 3: Determine Pedestrian Delay at Intersection

The pedestrian methodology in Chapter 18, Signalized Intersections, was used to estimate two pedestrian delay values. One value is the pedestrian delay at the boundary intersection when walking parallel to segment d_{pp}. This delay was computed to be 40 s/p. The second value is the pedestrian delay when crossing the segment at the nearest signal-controlled crossing d_{pc}. This delay was computed to be 80 s/p.

The pedestrian methodology in Chapter 19, Two-Way STOP-Controlled Intersections, was used to estimate the delay incurred while waiting for an acceptable gap in traffic d_{pw}. This delay was computed to be 740 s/p.

Step 4: Determine Pedestrian Travel Speed

The pedestrian travel speed is computed by using Equation 17-30.

$$S_{Tp,seg} = \frac{L}{\frac{L}{S_p} + d_{pp}}$$

$$S_{Tp,seg} = \frac{1{,}320}{\frac{1{,}320}{4.19} + 40}$$

$$S_{Tp,seg} = 3.72 \text{ ft/s}$$

This walking speed is slightly less than 4.0 ft/s and is considered acceptable, but a higher speed is desirable.

Step 5: Determine Pedestrian LOS Score for Intersection

The pedestrian methodology in Chapter 18 was used to determine the pedestrian LOS score for the downstream boundary intersection $I_{p,int}$. It was computed to be 3.60.

Step 6: Determine Pedestrian LOS Score for Link

The pedestrian LOS score for the link is computed from three factors. However, before these factors can be calculated, several cross-section variables need to be adjusted and several coefficients need to be calculated. These variables and coefficients are calculated first. Then, the three factors are computed. Finally, they are combined to determine the desired score.

The total width of the outside through lane, bicycle lane, and paved shoulder W_t is computed as

$$W_t = W_{ol} + W_{bl}$$

$$W_t = 12 + 5$$

$$W_t = 17 \text{ ft}$$

In fact, the variable W_t does not include the width of the paved outside shoulder in this instance because the proportion of occupied on-street parking exceeds 0.0.

The effective total width of the outside through lane, bicycle lane, and shoulder as a function of traffic volume W_v is equal to W_t because the midsegment flow rate is greater than 160 veh/h.

The street cross section is curbed, so the adjusted width of paved outside shoulder W_{os}^* is 8.0 ft (= 9.5 – 1.5).

Because the proportion of occupied on-street parking is less than 0.25, the effective width of the combined bicycle lane and shoulder W_1 is computed as

$$W_1 = W_{bl} + W_{os}^*$$

$$W_1 = 5 + 8$$

$$W_1 = 13 \text{ ft}$$

The adjusted available sidewalk width W_{aA} is computed as

$$W_{aA} = \min(W_T - W_{buf}, 10)$$

$$W_{aA} = \min(10 - 5, 10)$$

$$W_{aA} = 5.0 \text{ ft}$$

The sidewalk width coefficient f_{sw} is computed as

$$f_{sw} = 6.0 - 0.3\, W_{aA}$$

$$f_{sw} = 6.0 - 0.3(5.0)$$

$$f_{sw} = 4.5 \text{ ft}$$

The buffer area coefficient f_b is equal to 1.0 because there is no continuous barrier at least 3.0 ft high located in the buffer area.

The automobile methodology described in Section 2 was used to determine the motorized vehicle running speed S_R for the subject segment. This speed was computed to be 33.0 mi/h.

The cross-section adjustment factor is computed by using Equation 17-32.

$$F_w = -1.2276 \ln(W_v + 0.5\, W_1 + 50\, p_{pk} + W_{buf}\, f_b + W_{aA}\, f_{sw})$$

$$F_w = -1.2276 \ln(17 + 0.5\,(13) + 50\,(0.20) + 5.0\,(1.0) + 5.0\,(4.5))$$

$$F_w = -5.05$$

The motorized vehicle volume adjustment factor is computed by using Equation 17-33.

$$F_v = 0.0091 \frac{v_m}{4\,N_{th}}$$

$$F_v = 0.0091 \frac{940}{4\,(2)}$$

$$F_v = 1.07$$

The motorized vehicle speed adjustment factor is computed by using Equation 17-34.

$$F_s = 4\left(\frac{S_R}{100}\right)^2$$

$$F_s = 4\left(\frac{33.0}{100}\right)^2$$

$$F_s = 0.44$$

Finally, the pedestrian LOS score for the link $I_{p,link}$ is calculated by using Equation 17-31.

$$I_{p,link} = 6.0468 + F_w + F_v + F_S$$

$$I_{p,link} = 6.0468 + (-5.05) + 1.07 + 0.44$$

$$I_{p,link} = 2.51$$

Step 7: Determine Link LOS

The pedestrian LOS for the link is determined by using the pedestrian LOS score from Step 6 and the average pedestrian space from Step 2. These two performance measures are compared with their respective thresholds in Exhibit 17-3 to determine that the LOS for the specified direction of travel along the subject link is C.

Step 8: Determine Roadway Crossing Difficulty Factor

Crossings occur somewhat uniformly along the length of the segment and the segment is bounded by two signalized intersections. Thus, the distance D_c is assumed to equal one-third of the segment length, or 440 ft (= 1,320/3), and the diversion distance D_d is computed as 880 ft (= 2 × 440 ft).

The delay incurred due to diversion is calculated by using Equation 17-36.

$$d_{pd} = \frac{D_d}{S_p} + d_{pc}$$

$$d_{pd} = \frac{880}{4.19} + 80$$

$$d_{pd} = 290 \text{ s/p}$$

The crossing delay used to estimate the roadway crossing difficulty factor is computed as

$$d_{px} = \min(d_{pd}, d_{pw}, 60)$$

$$d_{px} = \min(290, 740, 60)$$

$$d_{px} = 60 \text{ s/p}$$

The roadway crossing difficulty factor is computed by using Equation 17-37.

$$F_{cd} = 1.0 + \frac{0.10\ d_{px} - (0.318\ I_{p,link} + 0.220\ I_{p,int} + 1.606)}{7.5} \leq 1.20$$

$$F_{cd} = 1.0 + \frac{0.10\ (60) - (0.318\ [2.51] + 0.220\ [3.60] + 1.606)}{7.5}$$

$$F_{cd} = 1.20$$

Step 9: Determine Pedestrian LOS Score for Segment

The pedestrian LOS score for the segment is computed by using Equation 17-38.

$$I_{p,seg} = F_{cd}\left(0.318\ I_{p,link} + 0.220\ I_{p,int} + 1.606\right)$$

$$I_{p,seg} = 1.20\ \left(0.318\ [2.51] + 0.220[3.60] + 1.606\right)$$

$$I_{p,seg} = 3.83$$

Step 10: Determine Segment LOS

The pedestrian LOS for the segment is determined by using the pedestrian LOS score from Step 9 and the average pedestrian space from Step 2. These two performance measures are compared with their respective thresholds in Exhibit 17-3 to determine that the LOS for the specified direction of travel along the subject segment is D.

EXAMPLE PROBLEM 3: BICYCLE LOS

The Segment

The bicycle lane of interest is located along a 1,320-ft urban street segment. The segment is part of a collector street located near a community college. The bicycle lane is provided for the eastbound direction of travel, as shown in Exhibit 17-40.

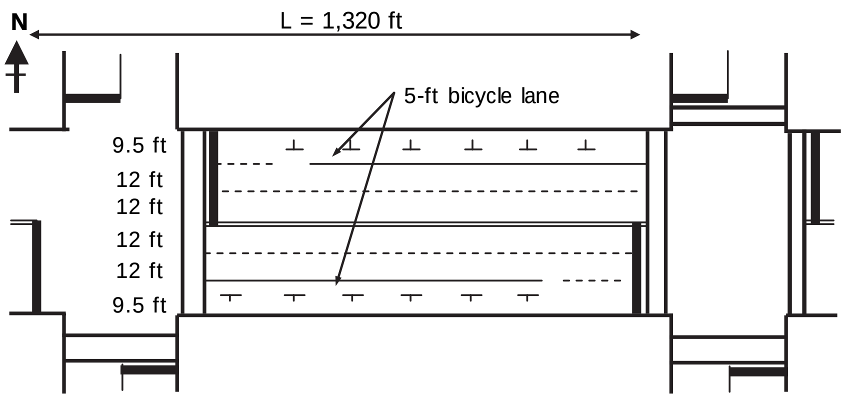


Exhibit 17-40
Example Problem 3: Segment Geometry

The Question

What is the bicycle LOS for the eastbound bicycle lane?

The Facts

The geometric details of the street cross section are shown in Exhibit 17-40. Both boundary intersections are signalized. The following additional information is known about the street segment:

Traffic Characteristics

Midsegment flow rate in eastbound direction: 940 veh/h

Percent heavy vehicles: 8.0%

Proportion of on-street parking occupied during analysis period: 0.20

Geometric Characteristics

Shoulder width consists of 8.0 ft for parking and 1.5 ft for gutter pan.

Cross section has raised curb along outside edge of roadway.

Number of access point approaches on right side of segment in subject travel direction: 3

Other Data

Pavement condition rating: 2.0

Performance Measures Obtained from Supporting Methodologies

Motorized vehicle running speed: 33 mi/h

Bicycle control delay: 40 s/bicycle

Bicycle LOS score for the downstream intersection: 0.08

Outline of Solution

First, the bicycle delay at the boundary intersection will be computed. This delay will then be used to compute the bicycle travel speed. Next, a bicycle LOS score will be computed for the link. It will then be combined with a similar score for the boundary intersection and used to compute the bicycle LOS score for the segment. Finally, LOS for the segment will be determined by using the computed score and the thresholds in Exhibit 17-4.

Computational Steps

Step 1: Determine Bicycle Running Speed

The average bicycle running speed S_b could not be determined from field data. Therefore, it was estimated to be 15 mi/h on the basis of the guidance provided.

Step 2: Determine Bicycle Delay at Intersection

The methodology in Chapter 18, Signalized Intersections, was used to estimate the bicycle delay at the boundary intersection d_b. This delay was computed to be 40.0 s/bicycle.

Step 3: Determine Bicycle Travel Speed

The segment running time of through bicycles is computed as

$$t_{Rb} = \frac{3{,}600\ L}{5{,}280\ S_b}$$

$$t_{Rb} = \frac{3{,}600\ (1{,}320)}{5{,}280\ (15)}$$

$$t_{Rb} = 60.0\ \text{s}$$

The average bicycle travel speed is computed by using Equation 17-39.

$$S_{Tb,seg} = \frac{3{,}600\ L}{5{,}280\ (t_{Rb} + d_b)}$$

$$S_{Tb,seg} = \frac{3{,}600\ (1{,}320)}{5{,}280\ (60.0 + 40.0)}$$

$$S_{Tb,seg} = 9.0\ \text{mi/h}$$

This travel speed is adequate, but a speed of 10 mi/h or more is considered desirable.

Step 4: Determine Bicycle LOS Score for Intersection

The bicycle methodology in Chapter 18 was used to determine the bicycle LOS score for the boundary intersection $I_{b,int}$. It was computed to be 0.08.

Step 5: Determine Bicycle LOS Score for Link

The bicycle LOS score is computed from four factors. However, before these factors can be calculated, several cross-section variables need to be adjusted. These variables are calculated first, and then the four factors are computed. Finally, they are combined to determine the desired score.

The total width of the outside through lane, bicycle lane, and paved shoulder W_t is computed as

$$W_t = W_{ol} + W_{bl}$$

$$W_t = 12 + 5$$

$$W_t = 17 \text{ ft}$$

In fact, the variable W_t does not include the width of the paved outside shoulder in this instance because the proportion of occupied on-street parking exceeds 0.0.

The effective total width of the outside through lane, bicycle lane, and shoulder as a function of traffic volume W_v is equal to W_t because the midsegment flow rate is greater than 160 veh/h.

The street cross section is curbed, so the adjusted width of paved outside shoulder W_{os}^* is 8.0 ft (= 9.5 – 1.5).

Because the combined bicycle lane and adjusted shoulder width exceed 4.0 ft, the effective width of the outside through lane is computed as

$$W_e = W_v + W_{bl} + W_{os}^* - 20\, p_{pk} \quad \geq 0.0$$

$$W_e = 17 + 5 + 8 - 20\,(0.20)$$

$$W_e = 26 \text{ ft}$$

The percent heavy vehicles is less than 50%, so the adjusted percent heavy vehicles P_{HVa} is equal to the input percent heavy vehicles P_{HV} of 8.0%.

The automobile methodology described in Section 2 was used to determine the motorized vehicle running speed S_R for the subject segment. This speed was computed to be 33.0 mi/h. This speed exceeds 21 mi/h, so the adjusted motorized vehicle speed S_{Ra} is also equal to 33.0 mi/h.

The midsegment demand flow rate is greater than 8 veh/h (= 4 N_{th}), so the adjusted midsegment demand flow rate v_{ma} is equal to the input demand flow rate of 940 veh/h.

The cross-section adjustment factor is computed by using Equation 17-41.

$$F_w = -0.005\, W_e^2$$

$$F_w = -0.005\,(26)^2$$

$$F_w = -3.38$$

The motorized vehicle volume adjustment factor comes from Equation 17-42.

$$F_v = 0.507 \ln\left(\frac{v_{ma}}{4\, N_{th}}\right)$$

$$F_v = 0.507 \ln\left(\frac{940}{4\,(2)}\right)$$

$$F_v = 2.42$$

The motorized vehicle speed adjustment factor is computed by using Equation 17-43.

$$F_S = 0.199\left[1.1199\ \ln(S_{Ra} - 20) + 0.8103\right](1 + 0.1038\ P_{HVa})^2$$

$$F_S = 0.199\left[1.1199\ \ln(33.0 - 20) + 0.8103\right](1 + 0.1038\ (8.0))^2$$

$$F_S = 2.46$$

The pavement condition adjustment factor is computed by using Equation 17-44.

$$F_p = \frac{7.066}{P_c^2}$$

$$F_p = \frac{7.066}{2.0^2}$$

$$F_p = 1.77$$

Finally, the bicycle LOS score for the link $I_{b,link}$ is calculated by using Equation 17-40.

$$I_{b,link} = 0.760 + F_w + F_v + F_S + F_p$$

$$I_{b,link} = 0.760 - 3.38 + 2.42 + 2.46 + 1.77$$

$$I_{b,link} = 4.02$$

Step 6: Determine Link LOS

The bicycle LOS for the link is determined by using the bicycle LOS score from Step 5. This performance measure is compared with the thresholds in Exhibit 17-4 to determine that the LOS for the specified direction of travel along the subject link is D.

Step 7: Determine Bicycle LOS Score for Segment

The bicycle LOS score for the segment is computed by using Equation 17-45.

$$I_{b,seg} = 0.160\ I_{b,link} + 0.011\ F_{bi}\ e^{I_{b,int}} + 0.035\ \frac{N_{ap,s}}{(L / 5{,}280)} + 2.85$$

$$I_{b,seg} = 0.160\ (4.02) + 0.011\ (1)\ e^{0.080} + 0.035\ \frac{3}{1{,}320 / 5{,}280} + 2.85$$

$$I_{b,seg} = 3.92$$

Step 8: Determine Segment LOS

The bicycle LOS for the segment is determined by using the bicycle LOS score from Step 7. This performance measure is compared with the thresholds in Exhibit 17-4 to determine that the LOS for the specified direction of travel along the subject segment is D.

EXAMPLE PROBLEM 4: TRANSIT LOS

The Segment

The transit route of interest travels east along a 1,320-ft urban street segment. The segment is part of a collector street located near a community college. It is shown in Exhibit 17-41. A bus stop is provided on the south side of the segment for the subject route.

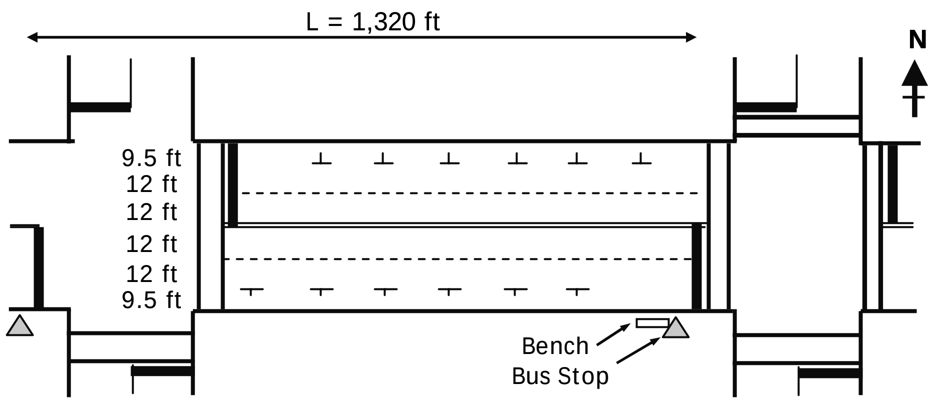


Exhibit 17-41
Example Problem 4: Segment Geometry

The Question

What is the transit LOS for the eastbound bus route while traveling the subject segment?

The Facts

The geometric details of the segment are shown in Exhibit 17-41. Both boundary intersections are signalized. There is one stop in the segment for the eastbound route. The following additional information is known about the bus stop and street segment:

Transit Characteristics

Dwell time: 20.0 s

Transit frequency: 4 veh/h

Excess wait time data are not available for the stop, but the on-time performance of the route (based on a standard of up to 5 min late being considered "on time") at the previous time point is known (92%).

Passenger load factor: 0.83 passengers/seat

Other Data

Area type: not in a central business district

The bus stop in the segment has a bench, but no shelter.

Number of routes serving the segment: 1

The bus stop is accessed from the right-turn lane (i.e., the stop is off-line). Buses are exempt from the requirement to turn right but have no other traffic priority.

Performance Measures Obtained from Supporting Methodologies

Motorized vehicle running speed: 33 mi/h

Pedestrian LOS score for the link: 3.53

Through control delay at downstream boundary intersection: 20.9 s/veh

Reentry delay: 16.17 s

g/C ratio at downstream boundary intersection: 0.4729

Outline of Solution

First, the transit vehicle segment running time will be computed. Next, the control delay at the boundary intersection will be obtained and used to compute the transit vehicle segment travel speed. Then, the transit wait–ride score will be computed. This score will be combined with the pedestrian LOS score for the link to compute the transit LOS score for the segment. Finally, LOS for the segment will be determined by comparing the computed score with the thresholds identified in Exhibit 17-4.

Computational Steps

Step 1: Determine Transit Vehicle Running Time

The transit vehicle running time is based on the segment running speed and delay due to a transit vehicle stop. These components are calculated first, and then running time is calculated.

Transit vehicle segment running speed can be computed by using Equation 17-46.

$$S_{Rt} = \min\left(S_R, \frac{61}{1 + e^{-1.00 + (1{,}185\,N_{ts}/L)}}\right)$$

$$S_{Rt} = \min\left(33.0, \frac{61}{1 + e^{-1.00 + (1{,}185\,[1]/1{,}320)}}\right)$$

$$S_{Rt} = 32.1\ \text{mi/h}$$

The acceleration and deceleration rates are unknown, so they are assumed to equal 4.0 ft/s^2.

The bus stop is located on the near side of a signalized intersection. From Equation 17-48, the average proportion of bus stop acceleration–deceleration delay not due to the intersection's traffic control f_{ad} is equal to the g/C ratio for the through movement in the bus's direction of travel (in this case, eastbound). The effective green time g is 47.29 s (calculated as the phase duration minus the change period), and the cycle length is 100 s. Therefore, f_{ad} is 0.4729.

Equation 17-47 can now be used to compute the portion of bus stop delay due to acceleration and deceleration.

$$d_{ad} = \frac{5{,}280}{3{,}600}\left(\frac{S_{Rt}}{2}\right)\left(\frac{1}{r_{at}} + \frac{1}{r_{dt}}\right) f_{ad}$$

$$d_{ad} = \frac{5{,}280}{3{,}600}\left(\frac{33.0}{2}\right)\left(\frac{1}{4.0}+\frac{1}{4.0}\right)(0.4729)$$

$$d_{ad} = 5.56 \text{ s}$$

Equation 17-49 is used to compute the portion of bus stop delay due to serving passengers, using the input average dwell time of 20.0 s and an f_{dt} value of 0.4729, based on the stop's near-side location at a traffic signal and the g/C ratio computed in a previous step. The f_{dt} factor is used to avoid double-counting the portion of passenger service time that occurs during the signal's red indication and is therefore included as part of control delay.

$$d_{ps} = t_d f_{dt}$$

$$d_{ps} = (20.0)(0.4729)$$

$$d_{ps} = 9.46 \text{ s}$$

The bus stop is located in the right-turn lane; therefore, the bus is subject to reentry delay upon leaving the stop. On the basis of the guidance for reentry delay for a near-side stop at a traffic signal, the reentry delay d_{re} is equal to the queue service time g_s. By following the procedures given in Chapter 18, Signalized Intersections, this time is calculated to be 16.17 s.

Equation 17-50 is used to compute the total delay due to the transit stop.

$$d_{ts} = d_{ad} + d_{ps} + d_{re}$$

$$d_{ts} = 5.56 + 9.46 + 16.17 = 31.19 \text{ s}$$

Equation 17-51 is used to compute transit vehicle running time on the basis of the previously computed components.

$$t_{Rt} = \frac{3{,}600\, L}{5{,}280\, S_{Rt}} + \sum_{i=1}^{N_{ts}} d_{ts,i}$$

$$t_{Rt} = \frac{3{,}600\ (1{,}320)}{5{,}280\ (32.1)} + 31.19$$

$$t_{Rt} = 59.3 \text{ s}$$

Step 2: Determine Delay at Intersection

The automobile control delay d at the boundary intersection was computed to be 20.9 s/veh.

Step 3: Determine Travel Speed

The average transit travel speed is computed by using Equation 17-53.

$$S_{Tt,seg} = \frac{3{,}600\, L}{5{,}280\, (t_{Rt} + d)}$$

$$S_{Tt,seg} = \frac{3{,}600\ (1{,}320)}{5{,}280\ (59.3 + 20.9)}$$

$$S_{Tt,seg} = 11.2 \text{ mi/h}$$

Step 4: Determine Transit Wait–Ride Score

The wait–ride score is based on the headway factor and the perceived travel time factor. Each of these components is calculated separately. The wait–ride score is then calculated.

The input data indicate that there is one route on the segment, and its frequency is 4 veh/h. The headway factor is computed by using Equation 17-54.

$$F_h = 4.00\ e^{-1.434/(v_s + 0.001)}$$

$$F_h = 4.00\ e^{-1.434/(4 + 0.001)}$$

$$F_h = 2.80$$

The perceived travel time factor is based on several intermediate variables that need to be calculated first. The first of these calculations is the amenity time rate. It is calculated by using Equation 17-58. A default passenger trip length of 3.7 mi is used in the absence of other information.

$$T_{at} = \frac{1.3\ p_{sh} + 0.2\ p_{be}}{L_{pt}}$$

$$T_{at} = \frac{1.3\ (0.0) + 0.2\ (1.0)}{3.7} = 0.054 \text{ min/mi}$$

Since no information is available for actual excess wait time, but on-time performance information is available for the route, Equation 17-59 is used to estimate excess wait time.

$$t_{ex} = [t_{late}(1 - p_{ot})]^2$$

$$t_{ex} = [5.0(1 - 0.92)]^2$$

$$t_{ex} = 0.16 \text{ min}$$

The excess wait time rate T_{ex} is then the excess wait time t_{ex} divided by the average passenger trip length L_{pt}: 0.16/3.7 = 0.043 min/mi.

The passenger load waiting factor is computed by using Equation 17-57.

$$a_1 = 1 + \frac{(4)(F_l - 0.80)}{4.2}$$

$$a_1 = 1 + \frac{(4)(0.83 - 0.80)}{4.2}$$

$$a_1 = 1.03$$

The perceived travel time rate is computed by using Equation 17-56.

$$T_{ptt} = \left(a_1 \frac{60}{S_{Tt,seg}} \right) + \left(2\, T_{ex} \right) - T_{at}$$

$$T_{ptt} = \left(1.03 \frac{60}{11.2} \right) + \left(2\, [0.043] \right) - 0.054$$

$$T_{ptt} = 5.53 \text{ min/mi}$$

The segment is not located in a central business district of a metropolitan area with a population of 5 million or more, so the base travel time rate T_{btt} is equal to 4.0 min/mi. The perceived travel time factor is computed by using Equation 17-55.

$$F_{tt} = \frac{(e-1)\, T_{btt} - (e+1)\, T_{ptt}}{(e-1)\, T_{ptt} - (e+1)\, T_{btt}}$$

$$F_{tt} = \frac{(-0.40-1)\,(4.0) - (-0.40+1)(5.53)}{(-0.40-1)\,(5.53) - (-0.40+1)\,(4.0)}$$

$$F_{tt} = 0.88$$

Finally, the transit wait–ride score is computed by using Equation 17-60.

$$s_{w-r} = F_h\, F_{tt}$$

$$s_{w-r} = (2.80)(0.88)$$

$$s_{w-r} = 2.46$$

Step 5: Determine Pedestrian LOS Score for Link

The pedestrian methodology described in Section 2 was used to determine the pedestrian LOS score for the link $I_{p,link}$. This score was computed to be 3.53.

Step 6: Determine Transit LOS Score for Segment

The transit LOS score for the segment is computed by using Equation 17-61.

$$I_{t,seg} = 6.0 - 1.50\, s_{w-r} + 0.15\, I_{p,link}$$

$$I_{t,seg} = 6.0 - 1.50\,(2.46) + 0.15\,(3.53)$$

$$I_{t,seg} = 2.84$$

Step 7: Determine LOS

The transit LOS is determined by using the transit LOS score from Step 6. This performance measure is compared with the thresholds in Exhibit 17-4 to determine that the LOS for the specified bus route is C.

5. REFERENCES

1. Bonneson, J. A., M. P. Pratt, and M. A. Vandehey. *Predicting the Performance of Automobile Traffic on Urban Streets: Final Report*. National Cooperative Highway Research Program Project 3-79. Texas Transportation Institute, Texas A&M University, College Station, Jan. 2008.
2. Dowling, R. G., D. B. Reinke, A. Flannery, P. Ryus, M. Vandehey, T. A. Petritsch, B. W. Landis, N. M. Rouphail, and J. A. Bonneson. *NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets*. Transportation Research Board of the National Academies, Washington, D.C., 2008.
3. Kittelson & Associates, Inc.; KFH Group, Inc.; Parsons Brinckerhoff Quade and Douglass, Inc.; and K. Hunter-Zaworski. *TCRP Report 100: Transit Capacity and Quality of Service Manual*, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C., 2003.
4. Federal Transit Administration. *Annual Data Publications.* National Transit Database. http://www.ntdprogram.gov/ntdprogram/. Accessed Sept. 1, 2008.
5. U.S. Department of Transportation. *2004 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance*. Washington, D.C., 2004. http://www.fhwa.dot.gov/policy/olsp/reportspubs.htm. Accessed Sept. 4, 2008.
6. Rouphail, N., J. Hummer, J. Milazzo, and D. Allen. *Capacity Analysis of Pedestrian and Bicycle Facilities: Recommended Procedures for the "Pedestrians" Chapter of the Highway Capacity Manual*. Report FHWA-RD-98-107. Federal Highway Administration, Washington, D.C., 1998.
7. Rouphail, N., J. Hummer, J. Milazzo, and D. Allen. *Capacity Analysis of Pedestrian and Bicycle Facilities: Recommended Procedures for the "Bicycles" Chapter of the Highway Capacity Manual*. Report FHWA-RD-98-108. Federal Highway Administration, Washington, D.C., 1998.
8. St. Jacques, K., and H. S. Levinson. *TCRP Report 26: Operational Analysis of Bus Lanes on Arterials*. Transportation Research Board, National Research Council, Washington, D.C., 1997.
9. Pline, J. (ed.). *Traffic Control Devices Handbook*. Institute of Transportation Engineers, Washington, D.C., 2001.
10. Koonce, P., L. Rodegerdts, K. Lee, S. Quayle, S. Beaird, C. Braud, J. Bonneson, P. Tarnoff, and T. Urbanik. *Traffic Signal Timing Manual*. Report No. FHWA-HOP-08-024. Federal Highway Administration, Washington, D.C., June 2008.
11. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C., 2009.
12. Zegeer, J. D., M. A. Vandehey, M. Blogg, K. Nguyen, and M. Ereti. *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses*. Transportation Research Board of the National Academies, Washington, D.C., 2008.