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NCHRP Project 17-87

Enhancing Pedestrian Volume Estimation and Developing HCM Pedestrian Methodologies for Safe and Sustainable Communities

Review Draft:
Chapter 18, Urban Street Segments (v6.0.1)

Prepared for:
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CHAPTER 18
URBAN STREET SEGMENTS

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

OVERVIEW

This chapter describes methodologies for evaluating the operation of each of the following urban street travel modes: motorized vehicle, pedestrian, bicycle, and transit. Each methodology is used to evaluate the quality of service provided to road users traveling along an urban street segment. A detailed description of each travel mode is provided in Chapter 2, Applications.

The methodologies are much more than just a means of evaluating quality of service. They include an array of performance measures that fully describe segment operation. These measures serve as clues in identifying operational issues and provide insight into the development of effective improvement strategies. The analyst is encouraged to consider the full range of measures associated with each methodology.

This chapter describes methodologies for evaluating urban street segment performance from the perspective of motorists, pedestrians, bicyclists, and transit riders. The methodologies are referred to as the motorized vehicle methodology, the pedestrian methodology, the bicycle methodology, and the transit methodology. Collectively, the methodologies can be used to evaluate an urban street segment operation from a multimodal perspective.

Each methodology in this chapter 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 along the urban street are described in Chapters 19 to 23.

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 motorized vehicle travel speed, motorized vehicle stop rate, automobile traveler perception score, pedestrian travel speed, pedestrian space, pedestrian level-of-service (LOS) score, bicycle travel speed, bicycle LOS score, transit vehicle travel speed, transit wait–ride score, and transit passenger LOS score.

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

CHAPTER ORGANIZATION

Section 2 of this chapter presents concepts used to describe urban street operation. It includes guidance for establishing the segment analysis boundaries and the analysis period duration and describes how an urban street segment is defined for the purpose of this chapter. It concludes with a discussion of the service measures and LOS thresholds used in the methodology.

Section 3 presents the methodology for evaluating motorized vehicle service along an urban street segment. It includes a description of the scope of the methodology and its required input data. It concludes with a description of the computational steps that are followed for each application of the methodology.

Section 4 presents the methodology for evaluating pedestrian service along an urban street segment. It includes a discussion of methodology scope, input data, and computational steps.

Section 5 presents the methodology for evaluating bicycle service along an urban street segment. It includes a discussion of methodology scope, input data, and computational steps.

Section 6 presents the methodology for evaluating transit rider service along an urban street segment. It includes a discussion of methodology scope, input data, and computational steps.

Section 7 presents guidance on using the results of the segment evaluation. It includes example results from each methodology and a discussion of situations in which alternative evaluation tools may be appropriate.

RELATED HCM CONTENT

Other *Highway Capacity Manual* (HCM) content related to this chapter includes the following:

- Chapter 16, Urban Street Facilities, which describes concepts and methodologies for the evaluation of an urban street facility;
- Chapter 17, Urban Street Reliability and ATDM, which provides a methodology for evaluating travel time reliability and guidance for using this methodology to evaluate alternative active traffic and demand management (ATDM) strategies;
- Chapter 19, Signalized Intersections, which provides methods for evaluating pedestrian and bicycle LOS at intersections, the results of which are used in this chapter’s facility-level pedestrian and bicycle methods;
- Chapter 29, Urban Street Facilities: Supplemental, which provides details of the reliability methodology, a procedure for sustained spillback analysis, information about the use of alternative evaluation tools, and example problems demonstrating both the urban street facility methodologies and the reliability methodology;
- Chapter 30, Urban Street Segments: Supplemental, which describes procedures for predicting platoon flow, spillback, and delay due to turns from the major street; a planning-level analysis application; and example problems demonstrating the urban street segment methodologies;
- Chapter 31, Signalized Intersections: Supplemental, which describes procedures for predicting actuated phase duration; lane volume distribution; saturation flow adjustment factors for pedestrian, bicycle, and work zone presence; and queue length; and presents a planning-level

analysis application, as well as example problems demonstrating the signalized intersection methodologies;

- Case Study 3, Krome Avenue, in the HCM Applications Guide in Volume 4, which demonstrates the application of HCM methods to the evaluation of a real-world urban street; and
- Section K, Urban Streets, in Part 2 of the *Planning and Preliminary Engineering Applications Guide to the HCM*, which describes how to incorporate this chapter's methods and performance measures into a planning or preliminary engineering effort.

A procedure for determining free-flow speed when a work zone is present along the segment is provided in the final report for NCHRP Project 03-107, Work Zone Capacity Methods for the HCM. This report is in the Technical Reference Library in online Volume 4.

Methodologies for quantifying the performance of a downstream boundary intersection are described in Chapters 19 to 23.

2. CONCEPTS

This section presents concepts used to describe urban street operation. The first subsection assists the analyst in determining the type of analysis to be conducted and includes guidance for establishing the segment analysis boundaries and the analysis period duration. The second describes how an urban street segment is defined in terms of points and links. The third discusses the service measures and LOS thresholds used in the methodology. The last identifies the scope of the collective set of methodologies.

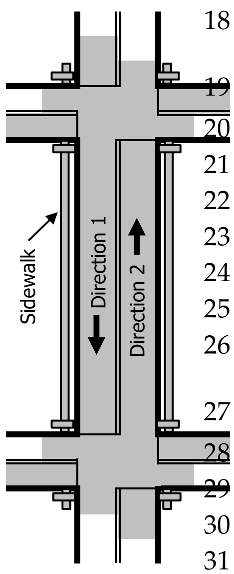
ANALYSIS TYPE

The phrase *analysis type* is used to describe the purpose for which a methodology is used. Each purpose is associated with a different level of detail, since it relates to the precision of the input data, the number of default values used, and the desired accuracy of the results. Three analysis types are recognized in this chapter:

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

These analysis types are discussed in more detail in Chapter 2, Applications.

Spatial and Temporal Limits



Legend
- analysis boundary

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

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 upstream from the intersection on each intersection leg. It includes all geometric features and traffic conditions that influence segment or intersection operation during the study period. For these reasons, the analysis boundaries should be established for each segment and intersection on the basis of the conditions present during the study period.

Travel Directions to Be Evaluated

Previous editions of the HCM have allowed the evaluation of one direction of travel along a segment (even when it served two-way traffic). That approach is retained in this edition 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 analysis of motorized vehicle 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 motorized vehicle methodology in this edition of the 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 this reason, evaluation of both travel directions on a two-way segment is important.

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.

URBAN STREET SEGMENT DEFINED

Terminology

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* is the boundary between links and is represented by an intersection or ramp terminal. A *link* is a length of roadway between two points. A link and its boundary points are referred to as a *segment.*

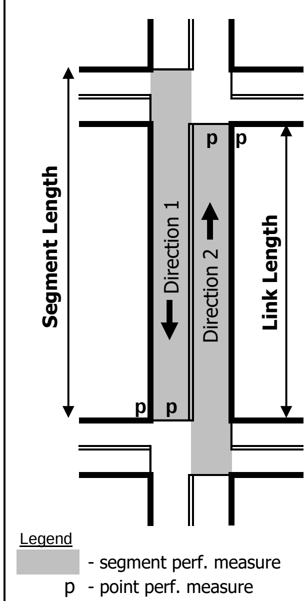
Points and Segments

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, 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, 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.

LOS CRITERIA

This subsection describes the LOS criteria for the motorized vehicle, pedestrian, bicycle, and transit modes. The criteria for the motorized vehicle mode are different from the criteria used for the other modes. Specifically, the criteria for the motorized vehicle mode are based on performance measures that are field-measurable and perceivable by travelers. With one exception, the criteria for the pedestrian and bicycle modes are based on scores reported by travelers indicating their perception of service quality. The exception is the pedestrian space measure (used with the pedestrian mode), which is field-measurable and perceivable by pedestrians. The criteria for the transit mode are based on measured changes in transit patronage due to changes in service quality.

Motorized Vehicle 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.

"Free-flow speed" is the average running speed of through vehicles traveling along a segment under low-volume conditions and not delayed by traffic control devices or other vehicles.

The "base free-flow speed" is defined to be the free-flow speed on longer segments.

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 80% 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 80% 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 18-1 lists the LOS thresholds established for the motorized vehicle mode on urban streets. The threshold value is interpolated when the base free-flow speed is between the values shown in the column headings of this exhibit. For example, the LOS A threshold for a segment with a base free-flow speed of 42 mi/h is 34 mi/h [= (42 – 40)/(45 – 40) × (36 – 32) + 32].

Exhibit 18-1
LOS Criteria: Motorized Vehicle Mode

LOS	Travel Speed Threshold by Base Free-Flow Speed (mi/h)							Volume-to-Capacity Ratio[a]
	55	50	45	40	35	30	25	
A	>44	>40	>36	>32	>28	>24	>20	≤ 1.0
B	>37	>34	>30	>27	>23	>20	>17	
C	>28	>25	>23	>20	>18	>15	>13	
D	>22	>20	>18	>16	>14	>12	>10	
E	>17	>15	>14	>12	>11	>9	>8	
F	≤17	≤15	≤14	≤12	≤11	≤9	≤8	
F	Any							> 1.0

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

Pedestrian, Bicycle, and Transit 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 in assessing 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 methodologies for evaluating the pedestrian, bicycle, and transit modes combine these factors to determine the corresponding mode's LOS.

The Spatial Limits subsections of Sections 4 and 5 provide guidance on when to use segment- and link-based analyses for the pedestrian and bicycle modes, respectively.

Pedestrian quality of service can be evaluated for the segment, the link, or both. A segment-based pedestrian evaluation uses the worse of the LOS letters resulting from pedestrian space and the segment pedestrian LOS score to determine the overall segment pedestrian LOS. The left side of Exhibit 18-2 lists the threshold values associated with each LOS for the segment-based evaluation of the pedestrian travel mode. The LOS 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 18-2
LOS Criteria: Pedestrian Mode

Segment-Based Pedestrian LOS Score	Segment-Based LOS by Average Pedestrian Space (ft²/p)						Link-Based Pedestrian LOS	
	>60	>40–60	>24–40	>15–24	>8.0–15[a]	≤8.0[a]	Link-Based LOS Score	LOS
≤2.00	A	B	C	D	E	F	≤1.50	A
>2.00–2.75	B	B	C	D	E	F	>1.50–2.50	B
>2.75–3.50	C	C	C	D	E	F	>2.50–3.50	C
>3.50–4.25	D	D	D	D	E	F	>3.50–4.50	D
>4.25–5.00	E	E	E	E	E	F	>4.50–5.50	E
>5.00	F	F	F	F	F	F	>5.50	F

Note: [a] In cross-flow situations, the LOS E/F threshold is 13 ft^2/p. Chapter 4 describes the concept of "cross flow" and situations where it should be considered.

A link-based pedestrian evaluation uses the link pedestrian score to determine the overall link pedestrian LOS. The right side of Exhibit 18-2 lists the threshold values associated with each LOS for the link-based evaluation of the pedestrian travel mode. The LOS is determined by consideration of only the LOS score.

Exhibit 18-3 lists the range of scores that are associated with each LOS for the bicycle and transit modes. Similar to the pedestrian mode, bicycle LOS can be evaluated for the link, the segment, or both. Transit LOS is only evaluated for the segment.

Exhibit 18-3
LOS Criteria: Bicycle and Transit Modes

LOS	Segment-Based Bicycle LOS Score	Link-Based Bicycle LOS Score	Transit LOS Score
A	≤2.00	≤1.50	≤2.00
B	>2.00–2.75	>1.50–2.50	>2.00–2.75
C	>2.75–3.50	>2.50–3.50	>2.75–3.50
D	>3.50–4.25	>3.50–4.50	>3.50–4.25
E	>4.25–5.00	>4.50–5.50	>4.25–5.00
F	>5.00	>5.50	>5.00

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.

SCOPE OF THE METHODOLOGIES

This subsection identifies the conditions for which each methodology is applicable.

- *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 motorized vehicle methodology can also be used to evaluate performance with all-way STOP- or YIELD-controlled (e.g., roundabout) boundary intersections.
- *Street types.* The four methodologies were developed with a focus on arterial and collector street conditions. If a methodology is used to

evaluate a local street, the performance estimates should be carefully reviewed for accuracy.

- *Flow conditions.* The four methodologies are based on the analysis of steady traffic conditions and are not well suited to the evaluation of unsteady conditions (e.g., congestion, cyclic spillback, signal preemption).
- *Target road users.* Collectively, the four methodologies were developed to estimate the LOS perceived by motorized vehicle 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.
- *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, 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.

3. MOTORIZED VEHICLE METHODOLOGY

This section describes the methodology for evaluating the capacity and quality of service provided to motorized vehicles on an urban street segment. Extensions to this methodology for evaluating more complex urban street operational elements are described in Chapter 30, Urban Street Segments: Supplemental.

SCOPE OF THE METHODOLOGY

The overall scope of the four methodologies was provided in Section 2. This section identifies the additional conditions for which the motorized vehicle methodology is applicable.

- *Target travel mode.* The motorized vehicle methodology addresses mixed automobile, motorcycle, truck, and transit traffic streams in which the automobile represents the largest percentage of all vehicles. The methodology is not designed to evaluate the performance of other types of vehicles (e.g., golf carts, motorized bicycles).
- *Mobility focus.* The motorized vehicle methodology is intended to facilitate the evaluation of mobility. Accessibility to adjacent properties by way of motorized vehicle 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.

Spatial and Temporal Limits

Analysis Boundaries

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 this reason, evaluation of both travel directions on a two-way segment is important.

The analysis boundary for each boundary intersection is defined by the operational influence area of the intersection. It should include the most distant extent of any intersection-related queue expected to occur during the study period. For these reasons, the influence area for a signalized intersection is likely to extend at least 250 ft back from the stop line on each intersection leg.

Study Period and Analysis Period

The concepts of *study period* and *analysis period* are defined in Section 2 in general terms. They are defined more precisely in this subsection as they relate to the motorized vehicle methodology.

Exhibit 18-4 demonstrates three alternative approaches an analyst might use for a given evaluation. Other alternatives exist, and the study period can exceed 1 h. Approach A is the approach that has traditionally been used and, unless otherwise justified, is the approach that is recommended for use.

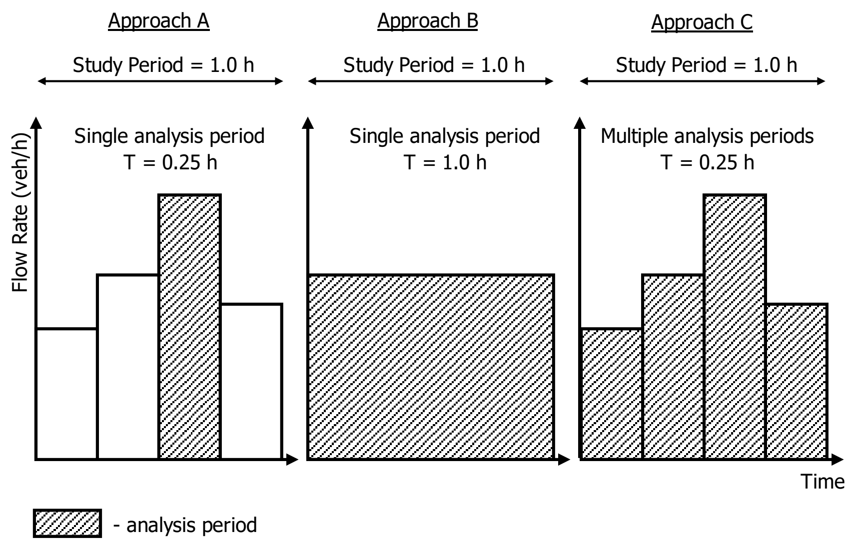


Exhibit 18-4
Three Alternative Study Approaches

Approach A is based on evaluation of the peak 15-min period during the study period. The analysis period *T* is 0.25 h. The equivalent hourly flow rate in vehicles per hour (veh/h) used for the analysis is based on either (*a*) a peak 15-min traffic count multiplied by four or (*b*) a 1-h demand volume divided by the peak hour factor. The former option is preferred for existing conditions when traffic counts are available; the latter option is preferred when hourly volumes are projected or when hourly projected volumes are added to existing volumes. Additional discussion on use of the peak hour factor is provided in the subsection titled Required Data and Sources.

The use of peak 15-min traffic multiplied by four is preferred for existing conditions when traffic counts are available. The use of a 1-h demand volume divided by a peak hour factor is preferred when volumes are projected or when hourly projected volumes have been added to existing volumes.

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 and for queues that carry over to the next analysis period. It produces a more accurate representation of delay. It is called "multiple time period analysis" and is described in the next subsection.

Regardless of analysis period duration, a single-period analysis (i.e., Approach A or B) is typical for planning applications.

Multiple Time Period Analysis

If the analysis period's demand volume exceeds capacity, a multiple time period analysis should be undertaken in which the study period includes an initial analysis period with no initial queue and a final analysis period with no residual queue. On a movement-by-movement and intersection-by-intersection basis, the initial queue for the second and subsequent periods is equal to the residual queue from the previous period. 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, 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.

Segment Length Considerations

The motorized vehicle methodology described in this section is not appropriate for the analysis of "short" segments that are bounded by signalized intersections. In contrast, the methodology described in Chapter 23, Ramp Terminals and Alternative Intersections, is appropriate for the analysis of short segments at signalized interchanges. The analyst may also consider using an alternative analysis tool that is able to model the operation of closely spaced intersections.

When a segment has a short length, the interaction between traffic movements and traffic control devices at the two boundary intersections is sufficiently complex that the motorized vehicle methodology may 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, the situation is particularly complicated when the two intersections are signalized.

Demand starvation occurs when a portion of the green at the downstream intersection is not used because the upstream intersection signalization prevents vehicles from reaching the stop line.

A short segment can experience "cyclic spillback." This spillback occurs when a queue extends back from one intersection into the other intersection (i.e., spills back) during a portion of each signal cycle and then subsides. A short segment can also experience "demand starvation." Demand starvation occurs when a portion of the green at the downstream intersection is not used because the upstream intersection signalization prevents vehicles from reaching the stop line. Demand starvation leads to the inefficient use of the downstream through phase and the retention of unserved vehicles on the approaches to the upstream intersection.

Specific conditions under which a segment bounded by signalized intersections should be considered "short" are difficult to define. As a general rule of thumb, cyclic spillback and demand starvation are unlikely to occur if the subject segment exceeds about 700 ft. They are also unlikely to occur on segments less than 700 ft *provided* that the following two conditions hold. First, the major traffic movement through the segment has coordinated signal timing that provides very favorable progression. Second, the coordinated traffic movement has about the same green-to-cycle-length ratio at each signal and each ratio is about 0.50 or larger. If the application of these rules to a specific segment indicates that cyclic spillback and starvation are unlikely to occur, the methodology described in this section can be used to evaluate the subject segment.

The methodology described in this section is applicable to segments having a length of 2 mi or less. This restriction is based on the fact that STOP-, YIELD-, or signal-controlled intersections are likely to have negligible effect on urban street operation when segment length exceeds 2 mi. Therefore, if a segment exceeds

2 mi in length, the analyst should evaluate it as an uninterrupted-flow highway segment with isolated intersections.

Performance Measures

Performance measures applicable to the motorized vehicle travel mode include travel speed, stop rate, and automobile traveler perception score. The latter measure provides an indication of the traveler's perception of service quality.

LOS is also considered a performance measure. It is useful for describing segment performance to elected officials, policy makers, administrators, or the public. LOS is based on travel speed and volume-to-capacity ratio.

Limitations of the Methodology

This subsection identifies the known limitations of the motorized vehicle methodology. If one or more of these limitations are believed to have an important influence on the performance of a specific street segment, the analyst should consider using alternative methods or tools for the evaluation.

The motorized vehicle methodology does not account for the effect of the following conditions on urban street operation:

The following parking-related effects are addressed in the methodology: (a) the effect on saturation flow rate of parking on the approach to a signalized intersection and (b) the effect on free-flow speed of parking stall presence along the street.

- Delay due to on-street parking maneuvers occurring along the link (see margin note for exceptions),
- Significant grade along the link,
- Queuing at the downstream boundary intersection backing up to and interfering with the operation of the upstream intersection or an access point intersection on a *cyclic* basis (e.g., as may occur at some interchange ramp terminals and closely spaced intersections),
- 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 19 to 23.

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 the motorized vehicle methodology in Chapter 19, Signalized Intersections. They are also used in the motorized vehicle methodology when the boundary intersection is signalized.

The motorized vehicle methodology in Chapter 19 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 established to facilitate data entry to the methodology. In this regard, input data describing intersection traffic are traditionally specific to the movement (e.g., left-turn movement volume) and not specific to the lane (e.g., analysts rarely have the volume for a lane shared by left-turning and through vehicles). 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).

REQUIRED DATA AND SOURCES

Additional required input data, potential data sources, and default values for the roundabout segment methodology can be found in Section 9 of Chapter 30.

This subsection describes the input data needed for the motorized vehicle methodology. The required data are listed in Exhibit 18-5. They must be separately specified for each direction of travel on the segment and for each boundary intersection. The exhibit also lists default values that can be used if local data are not available (*3*).

The entries in the first column in Exhibit 18-5 indicate 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 19 to 23).

The data elements listed in Exhibit 18-5 do not include variables that are considered to represent calibration factors (e.g., acceleration rate). A calibration factor typically has a relatively narrow range of reasonable values or has 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.

Traffic Characteristics Data

This subsection describes the traffic characteristics data listed in Exhibit 18-5. 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 19 to 23). The "count of vehicles" can be obtained from a variety of sources (e.g., from the field or as a forecast from a planning model).

Exhibit 18-5
Required Input Data, Potential Data Sources, and Default Values for Motorized Vehicle Analysis

Required Data and Units	Potential Data Source(s)	Suggested Default Value
Traffic Characteristics Data		
Demand flow rate by movement group at boundary intersection (veh/h)	Field data, past counts	Must be provided
Access point flow rate by movement group (veh/h)	Field data, past counts	See discussion in text
Midsegment flow rate (veh/h)	Field data, past counts	Estimate by using demand flow rate at the downstream boundary int. approach
Geometric Data		
Number of lanes by movement group at boundary intersection	Field data, aerial photo	Must be provided
Upstream intersection width (ft)	Field data, aerial photo	Must be provided
Segment approach turn bay length at boundary intersection (ft)	Field data, aerial photo	Must be provided
Number of midsegment through lanes	Field data, aerial photo	Must be provided
Number of lanes at access points—segment approach	Field data, aerial photo	(*a*) Number of through lanes on approach = number of midsegment through lanes. (*b*) No right-turn lanes. (*c*) If median present, one left-turn lane per approach; otherwise, no left-turn lanes.
Number of lanes at access points—access point approach	Field data, aerial photo	One left-turn and one right-turn lane
Segment approach turn bay length at access points (ft)	Field data, aerial photo	40% of the access point spacing, where spacing = 2 × (5,280) / D_a in feet, but not more than 300 ft nor less than 50 ft
Segment length (ft)	Field data, aerial photo	Must be provided
Restrictive median length (ft)	Field data, aerial photo	Must be provided
Proportion of segment with curb (decimal)	Field data, aerial photo	1.0 (curb present on both sides of segment)
Number of access point approaches	Field data, aerial photo	See discussion in text
Proportion of segment with on-street parking (decimal)	Field data	Must be provided
Other Data		
Analysis period duration (h)	Set by analyst	0.25 h
Speed limit (mi/h)	Field data, road inventory	Must be provided
Performance Measure Data		
Through control delay at boundary intersection (s/veh)	HCM method output	Must be provided
Through stopped vehicles at boundary intersection (veh)	HCM method output	Must be provided
2nd- and 3rd-term back-of-queue size for through movement at boundary intersection (veh/lane)	HCM method output	Must be provided
Capacity by movement group at boundary intersection (veh/h)	HCM method output	Must be provided
Midsegment delay (s/veh)	Field data	0.0 s/veh
Midsegment stops (stops/veh)	Field data	0.0 stops/veh

Notes: Int. = intersection.
D_a = access point density on segment (points/mi).

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.

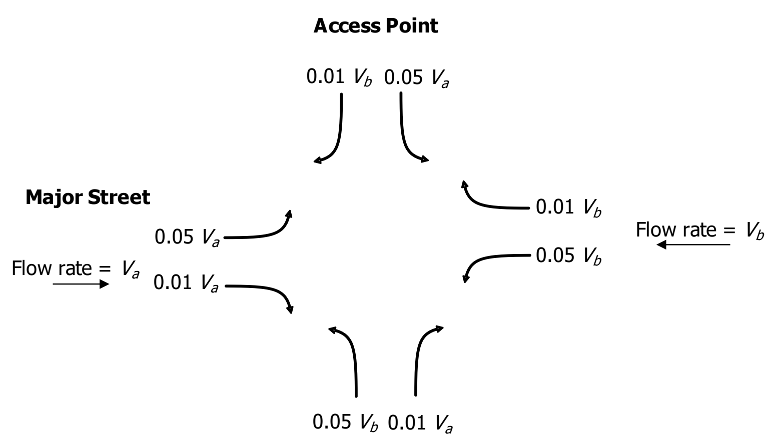
This flow rate is needed for all movements on each "active" access point approach and for all major-street movements at the intersection with one or more "active" access point approaches. An access point approach is considered to be *active* if its volume is sufficient to have some impact on segment 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 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.

If a planning analysis is being conducted in which (*a*) the projected demand flow rate coincides with a 1-h period and (*b*) an analysis of the peak 15-min period is desired, each movement's hourly demand should be divided by the intersection peak hour factor to predict the flow rate during the peak 15-min period. The peak hour factor should be based on local traffic peaking trends. If a local factor is not available, the default value in Exhibit 19-11 of Chapter 19 can be used.

Default value. 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 18-6 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 a typical access point density. They are applicable to access points serving any public-oriented land use (this excludes single-family residential land use and undeveloped property).

Exhibit 18-6
Default Turn Proportions for Access Point Intersections



If one of the movements shown in Exhibit 18-6 does not exist at a particular access point intersection, 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 through movement on an access point approach is not needed for the motorized vehicle methodology because this movement is considered to have negligible effect on major-street operation.

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, 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, it should be measured at several locations and an average used in the methodology.

If a planning analysis is being conducted in which (*a*) the projected demand flow rate coincides with a 1-h period and (*b*) an analysis of the peak 15-min period is desired, each movement's hourly demand should 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 subsection describes the geometric design data listed in Exhibit 18-5. These data describe the geometric elements of the segment or intersections that are addressed in the motorized vehicle methodology.

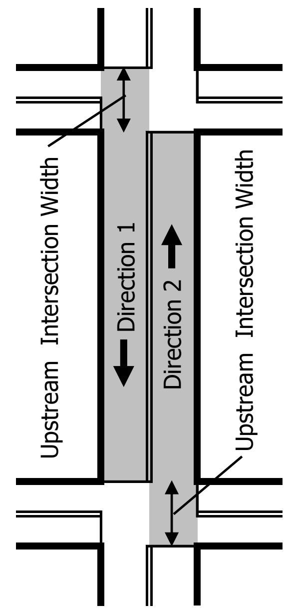
Number of Lanes at Boundary Intersection

The number of lanes at the boundary intersection is 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, the turn movement is indicated to have 0 lanes.

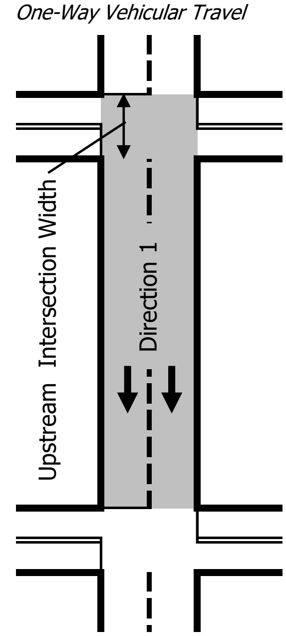
Upstream Intersection Width

The intersection width applies to the upstream boundary intersection for a given direction of travel and is the effective width of the cross street. On a two-way street, it is 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 is 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 at Boundary Intersection

Turn bay length is 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, 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, 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 on the Segment

The number of through lanes on the segment is 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.

If there is a midsegment lane restriction, the number of through lanes equals the number of lanes through the restriction. For example, if a work zone is present and it requires one through lane to be closed, the number of through lanes equals the count of through lanes that remain open through the work zone (and does not include the count of lanes that are closed).

Number of Lanes at Access Points

The number of lanes at an access point intersection is 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 the number of lanes at boundary intersections.

This input data element is needed for all movements on each active access point approach and for all major-street movements at the intersection with one or more active access point approaches. Guidance for determining whether an access point is “active” is provided in the section titled Access Point Flow Rate.

Turn Bay Length at Access Points

Turn bay length is 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.

This input data element is needed for all major-street turn movements at the intersection with one or more active access point approaches. Guidance for determining whether an access point is “active” is provided in the section titled Access Point Flow Rate.

Segment Length

Segment length is 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, 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 is 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 is the proportion of the link length with curb along the right side of the segment that is within 4 ft of the traveled way (i.e., within 4 ft of the nearest edge of traffic lane). This proportion is computed as the length of street with a curb present (and within 4 ft) divided by the link length. The length of street with a curb present 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 proportion is computed separately for each direction of travel along the segment.

Number of Access Point Approaches

The number of access point approaches along a segment is the count of *all* unsignalized driveway and public-street approaches to the segment, regardless of whether the access point is considered to be active. This number is counted separately for each side of the segment. It must equal or exceed the number of active access point approaches for which delay to segment through vehicles is computed. Guidance for determining whether an access point is “active” is provided in the section titled Access Point Flow Rate. 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.

Default value. When the number of access points is not known, it can be estimated from a specified access point density by using the following equation:

Equation 18-1

$$N_{ap,s} = 0.5\,\frac{D_a\,L}{5{,}280}$$

where $N_{ap,s}$ is the number of access point approaches on the right side in the subject direction of travel (points), D_a is the access point density on the segment (points/mi), and L is the segment length (feet). A default number of access points can be determined from the default access point density obtained from Exhibit 18-7.

Exhibit 18-7
Default Access Point Density Values

Area Type	**Median Type**	**Default Access Point Density (points/mi) by Speed Limit (mi/h)**						
		25	**30**	**35**	**40**	**45**	**50**	**55**
Urban	Restrictive	62	50	41	35	30	26	22
	Other	73	61	52	46	41	37	33
Suburban or rural	Restrictive	40	27	19	12	7	3	0
	Other	51	38	30	23	18	14	11

Proportion of Segment with On-Street Parking

The proportion of the segment with on-street parking is the proportion of the link length with parking stalls (either marked or unmarked) available along the right side of the segment. This proportion is computed as the length of street with parking stalls divided by the link length. Parking stalls considered include those described as having either a parallel or an angle design. This proportion is separately computed for each direction of travel along the segment.

Other Data and Performance Measures

This subsection describes the data listed in Exhibit 18-5 that are categorized as "other data" or "performance measure data."

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.

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.

Operational analysis. A 15-min analysis period should be used for operational analyses. This duration will accurately capture the adverse effects of demand peaks.

Planning analysis. A 15-min analysis period is used for most planning analyses. However, a 1-h analysis period can be used, if appropriate.

Speed Limit

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 concerning specification of speed limits. If the posted speed limit is known not to satisfy these assumptions, the speed limit value that is input to the methodology should be adjusted so that it is consistent with the assumptions.

Through Control Delay

The through control delay is 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 19 to 23, 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, 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 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, 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 is 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 19 to 23, depending on the type of control used at the intersection. Chapter 20, 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 18-2.

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

Equation 18-2

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 20-43 in Chapter 20. 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 19 to 23 provides capacity by lane group and the through movement is served in two or more lane groups, 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.

OVERVIEW OF THE METHODOLOGY

This subsection provides an overview of the methodology for evaluating the performance of the urban street segment in terms of its service to motorized vehicles. 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.

A planning-level analysis application for evaluating segment performance is provided in Section 5 of Chapter 30, Urban Street Segments: Supplemental. This method is not computationally intense and can be applied by using hand calculations.

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 motorized vehicle 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 motorized vehicle performance in noncoordinated systems.

The objective of this overview 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 Sections 2, 3, and 4 of 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 Section 7 of Chapter 30.

A methodology for evaluating the performance of the motorized vehicle mode on an urban street segment bounded by one or more roundabouts is provided in Section 9 of Chapter 30.

Exhibit 18-8 illustrates the calculation framework of the motorized vehicle methodology. It identifies the sequence of calculations needed to estimate selected performance measures. The calculation process flows from top to bottom in the exhibit. These calculations are described more fully in the next section.

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.

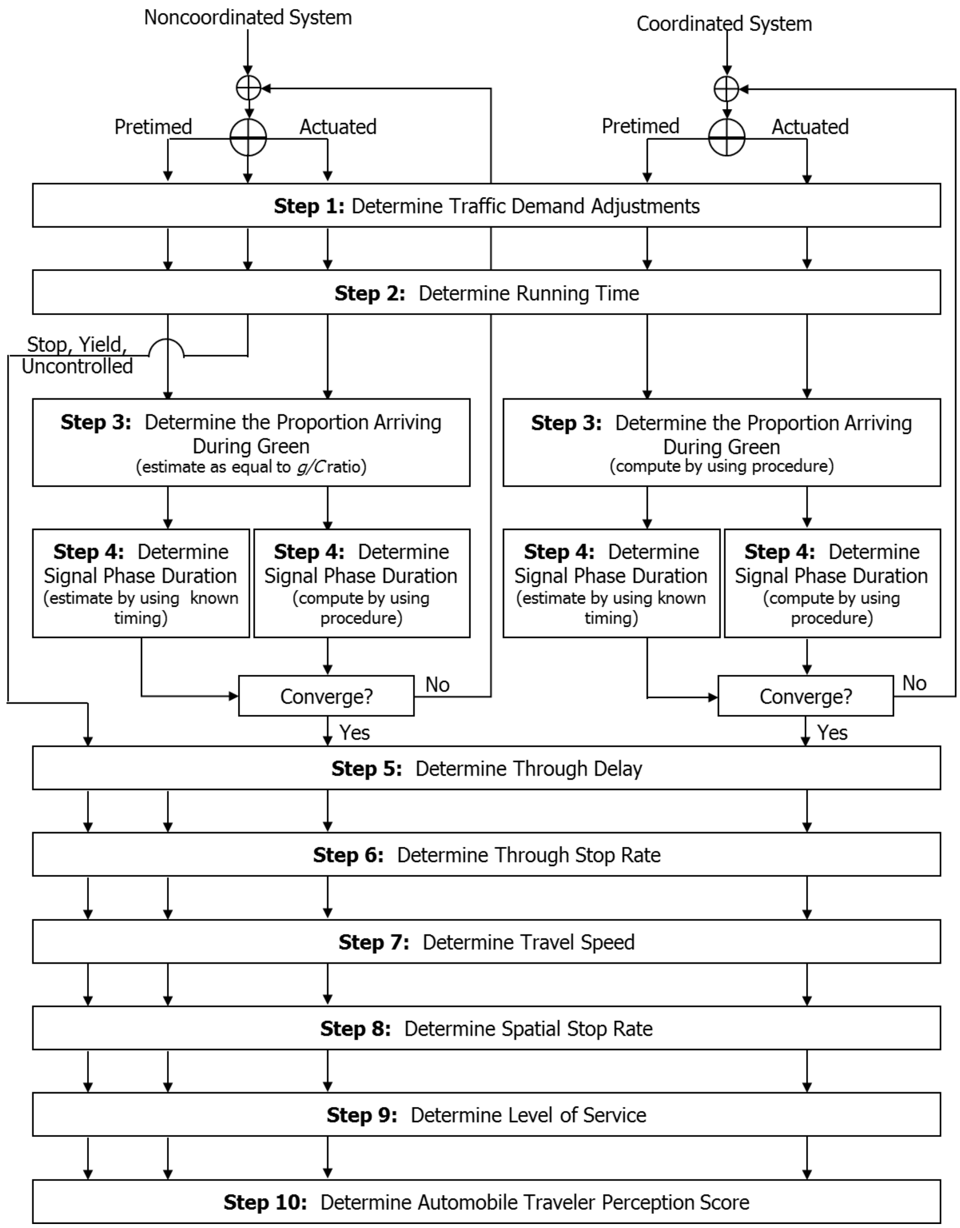
Details on the methodology for segments with roundabouts as boundary intersections can be found in Section 9 of Chapter 30.

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.

The methodology is shown to be iterative within Steps 1 to 4, with convergence achieved when the predicted discharge volume, phase duration, and capacity from successive iterations are effectively in agreement. Several iterations are typically needed for coordinated systems. In contrast, only one iteration is needed for noncoordinated systems unless there is a downstream lane closure (e.g., a midsegment work zone), in which case multiple iterations are needed to ensure that the vehicles discharged upstream of the lane closure do not exceed the lane closure capacity. The procedure for analyzing midsegment lane restrictions is described in Section 3 of Chapter 30.

Procedures in other chapters are needed to evaluate an urban street segment. For example, the procedure in Section 3 of Chapter 19 for computing actuated phase duration is needed for the analysis of actuated intersections on both coordinated and noncoordinated segments. Also, the procedure in Section 3 of Chapter 19 for computing control delay is needed for the estimation of segment through-movement delay. The capacity and control delay estimation procedures for roundabouts and all-way STOP-controlled intersections are needed from their respective chapters for the analysis of noncoordinated segments.

Exhibit 18-8
Motorized Vehicle Methodology for Urban Street Segments



COMPUTATIONAL STEPS

Step 1: Determine Traffic Demand Adjustments

During this step, various adjustments are undertaken to ensure that the volumes evaluated accurately reflect segment traffic conditions. The adjustments include (*a*) limiting entry to the segment because of 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.

The procedures for making the aforementioned adjustments and checks are described in Section 2 of Chapter 30. These adjustments and checks are not typically used for planning and preliminary engineering analyses. If spillback occurs, the sustained spillback procedure should be used. It is described in Section 3 of Chapter 29, Urban Street Facilities: Supplemental.

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, 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 and that at the adjacent intersection are taken at different times. They are also likely 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 so 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 18-9, which has four entry points and four exit points. There are three entry volumes at upstream Intersection A that contribute to three exit volumes at downstream Intersection B. There are also an entrance and an exit volume at the access point intersection located between the two intersections. The volume entering the segment, 1,350 veh/h, is the same as that exiting 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 18-10.

Exhibit 18-9
Entry and Exit Volume on Example Segment

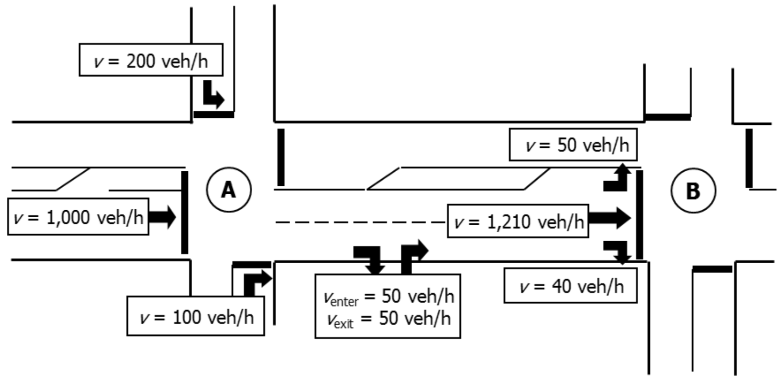


Exhibit 18-10
Example Origin–Destination Distribution Matrix

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 18-10 correspond to the entry volumes shown in Exhibit 18-9. The row totals in the last column of Exhibit 18-10 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 motorized vehicle 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. The methodology may not provide a reliable estimate of segment performance if cyclic spillback occurs.

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 sustained segment and bay spillback must be checked during this step. A procedure is described in Section 3 of Chapter 30 for this purpose. If the spillback does not occur during the analysis period (i.e., it never occurs, or it occurs after the analysis period), the methodology will provide a reliable estimate of segment performance.

A procedure is described in Section 3 of Chapter 29 for evaluating the occurrence of sustained segment spillback during the analysis period.

If turn bay spillback occurs during the analysis period, the methodology may not yield reliable performance estimates. In this situation, the analyst should consider either (*a*) reducing the analysis period so that it ends before spillback occurs or (*b*) using an alternative analysis tool that can 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 is the average running speed of through vehicles 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, curb presence, and on-street parking presence. It is computed by using Equation 18-3. Alternatively, it can be measured in the field by using the technique described in Section 6 of Chapter 30.

Equation 18-3

$$S_{fo} = S_{calib} + S_0 + f_{cs} + f_A + f_{pk}$$

where

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

S_{calib} = base free-flow speed calibration factor (mi/h),

S_0 = speed constant (mi/h),

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

f_A = adjustment for access points (mi/h), and

f_{pk} = adjustment for on-street parking (mi/h).

The speed constant and adjustment factors used in Equation 18-3 are listed in Exhibit 18-11 (*1*). Equations provided in the table footnote can also be used to compute these adjustment factors for conditions not shown in the exhibit.

Exhibit 18-11
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	Percent with On-Street Parking (%)	Adjustment for Parking (mi/h)[d]
0	0.0	0.0	0.0	0	0.0
2	−0.2	−0.1	−0.1	20	−0.6
4	−0.3	−0.2	−0.1	40	−1.2
10	−0.8	−0.4	−0.3	60	−1.8
20	−1.6	−0.8	−0.5	80	−2.4
40	−3.1	−1.6	−1.0	100	−3.0
60	−4.7	−2.3	−1.6		

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); L = segment length (ft); and W_i = width of signalized intersection (ft).
[d] $f_{pk} = -3.0 \times$ proportion of link length with on-street parking available on the right-hand side (decimal).

Equation 18-3 has been calibrated by using data for many urban street segments collectively located throughout the United States, so the default value of 0.0 mi/h for S_{calib} is believed to yield results that are reasonably representative of driver behavior in most urban areas. However, if desired, a locally representative value can be determined from field-measured estimates of the base free-flow speed for several street segments. The local default value can be established for typical street segments or for specific street types. This calibration factor is determined as the one value that provides a statistically based best-fit between the prediction from Equation 18-3 and the field-measured estimates. A procedure for estimating the base free-flow speed from field data is described in Section 6 of Chapter 30.

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 18-4 is used to compute the value of an adjustment factor that accounts for this influence.

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

Equation 18-4

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 18-4 was derived by using signalized boundary intersections. For more general applications, the definition of distance L_s is broadened so that it equals the distance between the two intersections that (*a*) bracket the subject segment and (*b*) have a type of control that can impose a legal requirement to stop or yield on the subject through movement.

Free-Flow Speed

The predicted free-flow speed is computed by using Equation 18-5 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.

$$S_f = S_{fo}\, f_L \geq S_{pl}$$

Equation 18-5

where S_f is the free-flow speed (mi/h), S_{pl} is the posted speed limit, and all other variables are as previously defined. The speed obtained from Equation 18-5 is always greater than or equal to the speed limit.

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 18-6 is used to compute the proximity adjustment factor.

Equation 18-6

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

where

f_v = proximity adjustment factor,

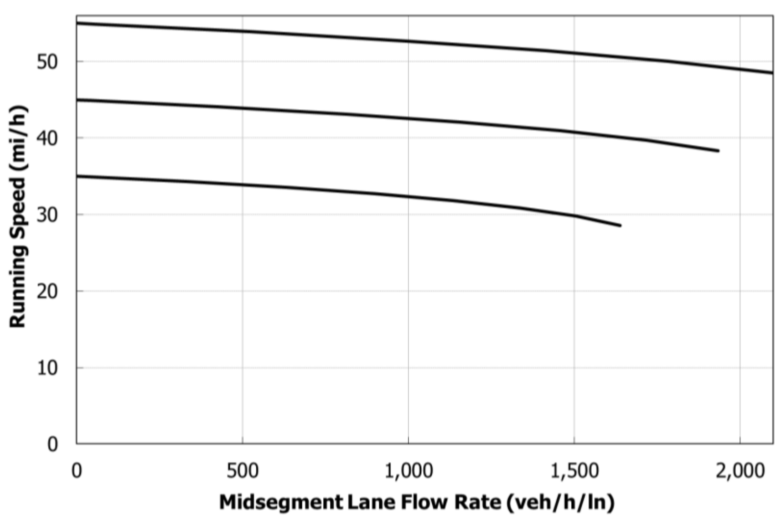
v_m = midsegment demand flow rate (veh/h),

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 18-12. 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, a volume in excess of this amount is unlikely to be experienced on a segment bounded by intersections at which the through movement is regulated by a traffic control device.

Exhibit 18-12
Speed–Flow Relationship for Urban Street Segments



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 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 Section 4 of Chapter 30.

For planning and preliminary engineering analyses, Exhibit 18-13 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 18-7).

Exhibit 18-13
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 18-13 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%, the delays can be reduced proportionally. For example, if the subject access point has 5% left turns and 5% right turns, 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, the values listed in the exhibit should be multiplied by 0.5. If both turn movements are provided a bay of adequate length, the delay due to turns can be assumed to equal 0.0 second per vehicle per access point (s/veh/pt).

D. Estimate Delay due to Other Sources

Numerous other factors could cause a driver traveling along a segment to reduce speed or to incur delay. 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.

Among the many sources of midsegment delay, the motorized vehicle 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, it can be included in the equation to compute running time.

E. Compute Segment Running Time

Equation 18-7 is used to compute segment running time on the basis of consideration of through movement control at the boundary intersection, free-flow speed, vehicle proximity, and various midsegment delay sources.

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

Equation 18-7

with

Equation 18-8

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

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).

The variables l_1, f_x, v_{th}, and c_{th} used with the first term in Equation 18-7 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, 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). That procedure is described in this step. The platoon ratio (as described in Section 3 of Chapter 19, Signalized Intersections) should be used to compute this proportion 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), 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, 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, 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 18-8. 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, the major-street through, and the 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 18-14 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 Section 3 of Chapter 30.

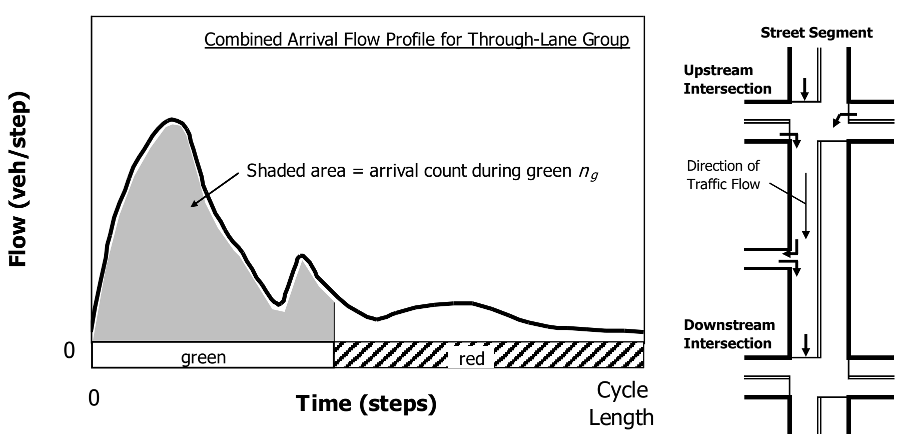


Exhibit 18-14
Use of an Arrival Flow Profile to Estimate the Volume Arriving During Green

The gray shaded area in Exhibit 18-14 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 with Equation 18-9.

Equation 18-9

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

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).

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, this step is skipped.

If the downstream boundary intersection has pretimed signal control, the signal phase duration is an input value. If this intersection has some form of actuated control, the procedure described in Section 3 of Chapter 19 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 is the sum of two delay sources. One source, called control delay, is the delay due to the traffic control at the boundary intersection. The other, called geometric delay, is that due to the negotiation of intersection geometry, such as curvature.

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

- Signal control (Chapter 19 or 23),
- All-way STOP control (Chapter 21), and
- YIELD control at a roundabout intersection (Chapter 22).

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, 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 roundabout is not negligible. This delay can be estimated by using the procedure provided in Section 9 of Chapter 30.

If the segment is not in a coordinated system, the through delay estimate should be based on isolated operation. The methodologies in Chapters 19 to 22 can be used to provide this estimate.

If the segment is within a coordinated signal system, the methodology in Chapter 19 (for most signalized intersections) or Chapter 23 (for signalized ramp terminals and alternative intersections) 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 equation for calculating this factor is described in Section 3 of Chapter 19.

If the through movement shares one or more lanes at a signalized boundary intersection, the through delay is computed by using Equation 18-10.

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

Equation 18-10

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 Section 2 of Chapter 31, Signalized Intersections: Supplemental, is used to estimate the variables shown in Equation 18-10.

Step 6: Determine Through Stop Rate

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 incurred by through vehicles from those incurred by nonthrough vehicles. However, the 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, 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 18-11.

Equation 18-11

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

with

Equation 18-12

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

Equation 18-13

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

Equation 18-14

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

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).

The procedure for computing N_f, Q_2, and Q_3 is provided in Section 4 of Chapter 31, Signalized Intersections: Supplemental.

The first term in Equation 18-11 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, $N_{f,i}$ 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 18-11 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 18-15 is used to compute the travel speed for the subject direction of travel along the segment.

Equation 18-15

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

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 delay used in Equation 18-15 is that incurred by the through lane group at the downstream boundary intersection.

Step 8: Determine Spatial Stop Rate

Spatial stop rate is the stop rate expressed in units of stops per mile. It provides an equitable means of comparing the performance of alternative street segments with differing lengths. Equation 18-16 is used to compute the spatial stop rate for the subject direction of travel along the segment.

Equation 18-16

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

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 18-16 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, it can be included in the calculation by using the variable h_{other}.

Step 9: Determine LOS

LOS is determined separately for both directions of travel along the segment. Exhibit 18-1 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. The second is the volume-to-capacity ratio for the through movement at the downstream boundary intersection.

The travel speed LOS threshold value is shown in Exhibit 18-1 to be dependent on the base free-flow speed. 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 determined in this step applies to the overall segment for the subject direction of travel. This LOS describes conditions for the combined link and downstream boundary intersection. If desired, the methodologies in Chapters 19 to 23 can be used to determine the LOS for travel through just the downstream boundary intersection. The HCM does not include a methodology for describing the LOS for just 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 with Equation 18-17 to Equation 18-22.

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

Equation 18-17

with

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

Equation 18-18

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

Equation 18-19

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

Equation 18-20

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

Equation 18-21

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

Equation 18-22

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).

The derivation of Equation 18-17 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 18-17 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 18-17 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.

4. PEDESTRIAN METHODOLOGY

This section describes the methodology for evaluating the quality of service provided to pedestrians traveling along an urban street segment.

SCOPE OF THE METHODOLOGY

The overall scope of the four methodologies was provided in Section 2. This section identifies the additional conditions for which the pedestrian methodology is applicable.

- *Target travel modes.* The pedestrian methodology addresses travel by walking in the urban street right-of-way. It is not designed to evaluate the performance of other travel means (e.g., Segway, roller skates).
- *"Typical pedestrian" focus.* The pedestrian methodology is not designed to reflect the perceptions of any particular pedestrian subgroup, such as pedestrians with disabilities. 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.

Spatial Limits

Travel Directions to Be Evaluated

Urban street 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, pedestrians are assumed to walk in the street on the subject side (even if there is a sidewalk on the other side).

The typical evaluation will focus on the performance of the segment (i.e., the link and boundary intersection combined). However, in some situations, an evaluation of just the link is appropriate. Each approach is discussed in this subsection.

Segment-Based Evaluation

For a segment-based evaluation, the pedestrian methodology considers the performance of the link and the boundary intersection. It is applied through a series of 10 steps culminating in the determination of the segment LOS.

A segment-based evaluation considers both pedestrian space and a pedestrian LOS score to determine segment LOS. It uses the worse of the LOS letters resulting from pedestrian space and the segment pedestrian LOS score to determine the overall segment pedestrian LOS. A segment-based evaluation is recommended for analyses that compare the LOS of multiple travel modes because each mode's segment LOS score and letter can be directly compared.

Pedestrian space reflects the level of crowding on the sidewalk. Pedestrian space typically only influences overall pedestrian LOS when pedestrian facilities are very narrow, pedestrian volumes are very high, or both. For example, with an effective sidewalk width of 4 ft, pedestrian volumes need to be in excess of 1,000 pedestrians per hour for the space-based pedestrian LOS to drop below LOS A. Pedestrian space is not applicable when the pedestrian facility does not exist.

The methodology supports the analysis of a segment with either signal-controlled or two-way STOP-controlled boundary intersections. Section 5 of Chapter 19 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.

Link-Based Evaluation

Only two of the 10 steps of the pedestrian methodology are used 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., pedestrian space, crossing difficulty, or intersection service). For this reason, the LOS score for the link should not be aggregated to characterize facility performance. The analyst should also be aware that this approach precludes an integrated multimodal evaluation because it does not reflect all aspects of segment performance.

Performance Measures

Performance measures applicable to the pedestrian travel mode include pedestrian travel speed, pedestrian space, and pedestrian LOS score. The LOS score is an indication of the typical pedestrian's perception of the overall segment travel experience.

LOS is also considered a performance measure. It is useful for describing segment performance to elected officials, policy makers, administrators, or the public. LOS is based on pedestrian space and pedestrian LOS score.

"Pedestrian space" is 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 18-15 provides a qualitative description of pedestrian space that can be used to evaluate sidewalk performance from a circulation-area perspective.

Exhibit 18-15
Qualitative Description of Pedestrian Space

Pedestrian Space (ft^2/p) Random Flow	Pedestrian Space (ft^2/p) 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 18-15 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.

Limitations of the Methodology

This subsection identifies the known limitations of the pedestrian methodology. If one or more of these limitations are believed to have an important influence on the performance of a specific street segment, the analyst should consider using alternative methods or tools for the evaluation.

The pedestrian methodology does not account for the effect of the following conditions on the quality of service provided to pedestrians:

- Segments bounded by an all-way STOP-controlled intersection, roundabout, or signalized interchange ramp terminal;
- 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;
- Points where a high volume of vehicles cross the sidewalk, such as a parking garage entrance; and
- Presence of railroad crossings.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the pedestrian methodology. The required data are listed in Exhibit 18-16. They must be separately specified for each direction of travel on the segment and for each boundary intersection. The exhibit also lists default values that can be used if local data are not available (*2*, *3*).

The data elements listed in Exhibit 18-16 do not include variables that are considered to represent calibration factors. A calibration factor typically has a relatively narrow range of reasonable values or has 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 18-16
Required Input Data, Potential Data Sources, and Default Values for Pedestrian Analysis

Required Data and Units	Potential Data Source(s)	Suggested Default Value
	Traffic Characteristics	
Midsegment motorized vehicle flow rate[a] (veh/h)	Field data, past counts, forecasts	Must be provided
Midsegment pedestrian flow rate (p/h)	Field data, past counts	Must be provided
Proportion of on-street parking occupied (decimal)	Field data	0.50 (if parking lane present)
	Geometric Design	
Downstream intersection width[a] (ft)	Field data, aerial photo	Must be provided
Segment length[a] (ft)	Field data, aerial photo	Must be provided
Number of midsegment through lanes[a]	Field data, aerial photo	Must be provided
Outside through lane width (ft)	Field data, aerial photo	12 ft
Bicycle lane width (ft)	Field data, aerial photo	5.0 ft (if provided)
Paved outside shoulder width (ft)	Field data, aerial photo	Must be provided
Striped parking lane width (ft)	Field data, aerial photo	8.0 ft (if provided)
Curb presence (yes or no)	Field data, aerial photo	Must be provided
Sidewalk presence (yes or no)	Field data, aerial photo	Must be provided
Total walkway width (ft)	Field data, aerial photo	9.0 ft (business/office uses) 11.0 ft (residential/industrial uses)
Effective width of fixed objects (ft)	Field data	2.0 ft inside, 2.0 ft outside (business/office uses) 0.0 ft inside, 0.0 ft outside (residential/industrial uses)
Buffer width (ft)	Field data, aerial photo	0.0 ft (business/office uses) 6.0 ft (residential/industrial uses)
Spacing of objects in buffer (ft)	Field data, aerial photo	Must be provided
	Other Data	
Distance to nearest signal-controlled crossing (ft)	Field data, aerial photo	One-third the distance between signal-controlled crossings that bracket the segment
Legality of midsegment pedestrian crossing (legal or illegal)	Field data, local traffic laws	Must be provided
Proportion of sidewalk adjacent to window, building, or fence (decimal)	Field data	0.0 (non-CBD area) 0.5 building, 0.5 window (CBD)
	Performance Measures	
Motorized vehicle midsegment running speed[a] (mi/h)	HCM method output	Must be provided
Pedestrian delay at boundary intersection (s/p)	HCM method output	Must be provided
Pedestrian delay at midsegment signalized crosswalk (s/p)	HCM method output	20 s/p (if present)
Pedestrian delay at uncontrolled crossing (s/p)	HCM method output	Must be provided
Pedestrian LOS score for intersection (decimal)	HCM method output	Must be provided

Notes: CBD = central business district; p = person.
[a] Also used or calculated by the motorized vehicle methodology.

Traffic Characteristics Data

This subsection describes the traffic characteristics data listed in Exhibit 18-16. These data describe the motorized vehicle and pedestrian traffic streams traveling along the segment during the analysis period. Midsegment flow rate is defined in a similarly titled section for the motorized vehicle methodology.

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. The use of pavement markings to delineate the parking lane should also be noted.

If parking is not allowed on the segment, the proportion equals 0.0. If parking is allowed along the segment but the spaces are not used during the analysis period, 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, the proportion equals 0.50.

Geometric Design Data

This subsection describes the geometric design data listed in Exhibit 18-16. These data describe the geometric elements that influence pedestrian 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 and number of through lanes are defined in a similarly titled section for the motorized vehicle methodology.

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 is 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 is 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, Outside Shoulder, Parking Lane

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), paved outside shoulder, and striped parking lane.

The outside lane width does not include the width of the gutter. If curb and gutter are present, 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).

Curb Presence

The presence of a curb on the right side edge of the roadway is determined for each segment travel direction.

Presence of a Sidewalk

A sidewalk is a paved walkway that is provided at the side of the roadway. Pedestrians are assumed to 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, 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 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 24, 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 is 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, the average spacing of objects that are 3 ft or more in height should also be recorded.

Other Data

This subsection describes the data listed in Exhibit 18-16 that are categorized as “other data.”

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 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.

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 making this crossing at any point is illegal, 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 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.

Performance Measures

This subsection describes the data listed in Exhibit 18-16 that are categorized as "performance measures."

Motorized Vehicle Running Speed

The motorized vehicle running speed is based on the segment running time obtained from the motorized vehicle methodology. The running speed is equal to the segment length divided by the segment running time.

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 Section 3 of Chapter 19 is used to compute this delay.

The second delay variable 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, the procedure described in Section 3 of Chapter 19 is used to compute this delay. If the nearest crossing is at a midsegment signalized crosswalk, this delay should equal the pedestrian's average wait for service after the pedestrian push button is pressed. This wait will depend on the signal settings and could range from 5 to 25 seconds per 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, the pedestrian waiting delay is determined by using the procedure in Chapter 20, Two-Way STOP-Controlled Intersections. If it is illegal, the pedestrian waiting delay does not need to be calculated.

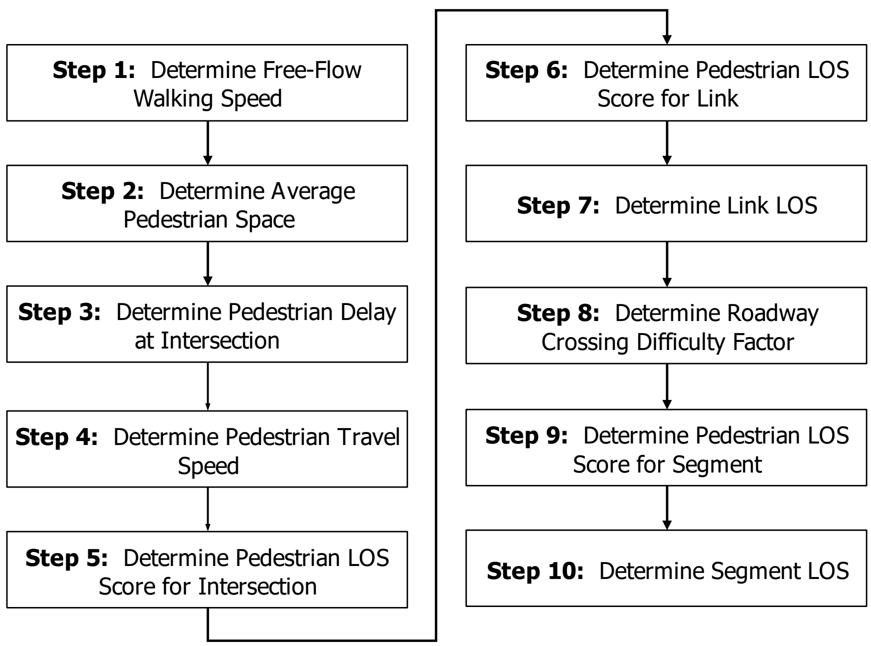
Pedestrian LOS Score for Intersection

The pedestrian LOS score for the signalized intersection is obtained from the pedestrian methodology in Chapter 19.

OVERVIEW OF THE METHODOLOGY

This subsection provides an overview of the methodology for evaluating the performance of an urban street segment in terms of its service to pedestrians. The methodology consists of 10 calculation steps. These steps are illustrated in Exhibit 18-17. All 10 steps are completed for a typical segment-based evaluation. Only Steps 6 and 7 are needed for a link-based evaluation.

Exhibit 18-17
Pedestrian Methodology for Urban Street Segments



A methodology for evaluating off-street pedestrian facilities is provided in Chapter 24, Off-Street Pedestrian and Bicycle Facilities.

COMPUTATIONAL STEPS

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 (*4*). 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 18-23 to Equation 18-27.

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

Equation 18-23

with

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

Equation 18-24

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

Equation 18-25

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

Equation 18-26

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

Equation 18-27

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),

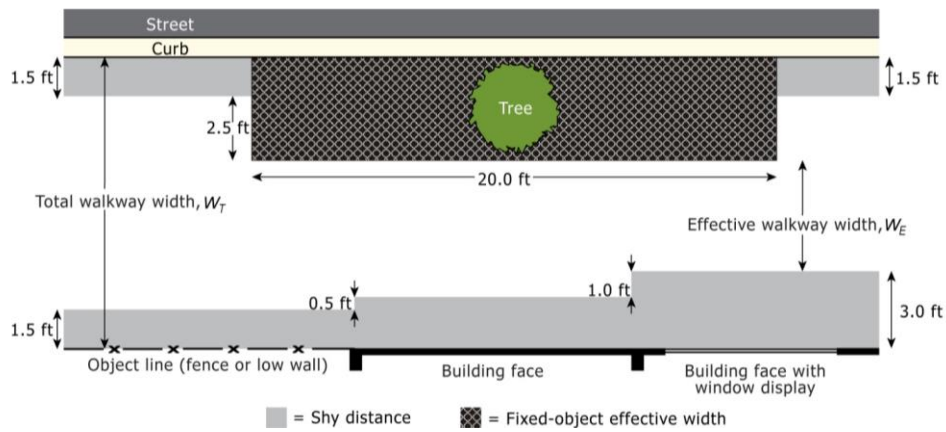
p_{fence} = proportion of sidewalk length adjacent to a fence or low wall (decimal),

$w_{O,i}$ = 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 18-18.

Exhibit 18-18
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 24, 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 18-18. 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 a 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 18-28 for the subject sidewalk. The variable v_{ped} is an input variable.

Equation 18-28

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

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 18-29. This equation is derived from the relationship between flow rate and average walking speed described in Exhibit 24-1 of Chapter 24.

Equation 18-29

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

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

D. Compute Pedestrian Space

Finally, Equation 18-30 is used to compute average pedestrian space.

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

Equation 18-30

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

The pedestrian space obtained from Equation 18-30 can be compared with the ranges provided in Exhibit 18-15 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 is an input variable for the methodology and is described in the previous subsection titled Required Data and Sources.

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

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 and the time required to walk the length of the segment. Thus, it is typically slower than the average walking speed. The pedestrian travel speed is computed by using Equation 18-31.

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

Equation 18-31

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 incurred in 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, the pedestrian methodology described in Chapter 19 is used for this determination. If the boundary intersection is two-way STOP controlled, the score is equal to 0.0.

Step 6: Determine Pedestrian LOS Score for Link

The pedestrian LOS score for the link $I_{p,\text{link}}$ is calculated with Equation 18-32.

Equation 18-32

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

with

Equation 18-33

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

Equation 18-34

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

Equation 18-35

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

where

$I_{p,\text{link}}$ = 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 18-19) (ft);

W_l = total width of shoulder, bicycle lane, and parking lane (see Exhibit 18-19) (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_T = total walkway width (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 18-33 to Equation 18-35 is dependent on various conditions. These conditions are identified in Column 1 of Exhibit 18-19. If the condition is satisfied, the equation in Column 2 is used to compute the variable value. If it is not satisfied, 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 18-19
Variables for Pedestrian LOS Score for Link

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
$v_m > 160$ veh/h or $W_A > 0$ ft	$W_v = W_{ol} + W_{bl} + W_{os}^* + W_{pk}$	$W_v = (W_{ol} + W_{bl} + W_{os}^* + W_{pk}) \times (2 - 0.005\ v_m)$
$p_{pk} > 0.25$ or $W_{bl} + W_{os}^* + W_{pk} \leq 10$	$W_l = W_{bl} + W_{os}^* + W_{pk}$	$W_l = 10$

Notes: 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);
W_{bl} = width of the bicycle lane = 0.0 if bicycle lane not provided (ft); and
W_{pk} = width of striped parking lane (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 18-18 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 and 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, 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 18-32. 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 $I_{p,\text{link}}$ 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 motorized vehicle methodology, as described in Section 3.

Step 7: Determine Link LOS

The pedestrian LOS for the link is determined by using the pedestrian LOS score from Step 6. This score is compared with the link-based pedestrian LOS thresholds on the right side of Exhibit 18-2 to determine the LOS for the specified direction of travel along the subject link.

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 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, 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 the option requiring the least perceived 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.

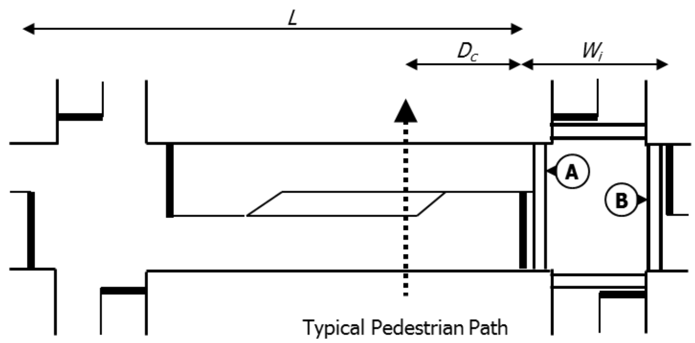
The delay incurred as a consequence of diverting to the nearest signal-controlled crossing is computed first. It includes the delay involved in walking to and from the midsegment crossing point to the nearest signal-controlled crossing and the delay waiting to cross at the signal. Hence, calculation 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 18-20. Exhibit 18-20(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.

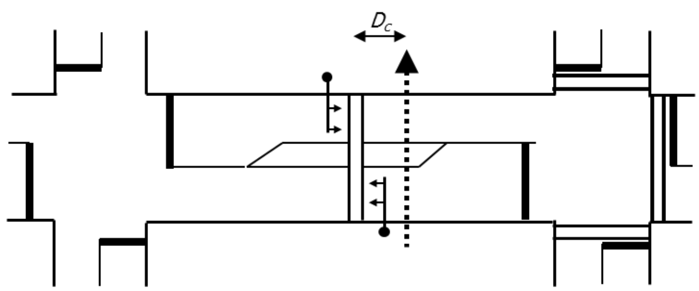
Exhibit 18-20(b) illustrates the distance D_c when a signalized crosswalk is provided at a midsegment location. In this situation, the distance is measured from the pedestrian crossing location to the location of the signalized crosswalk. In either case, the distance D_c is an input value provided by 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.

Exhibit 18-20
Diversion Distance Components



(a) Divert to Nearest Boundary Intersection



(b) Divert to Midsegment Signalized Crosswalk

The diversion distance to the nearest crossing is computed with Equation 18-36.

Equation 18-36

$$D_d = 2\ D_c$$

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 18-20(a), Equation 18-36 applies directly. If the nearest crossing location is at the signalized intersection but the crossing is at Location B, the distance obtained from Equation 18-36 should be increased by adding two increments of the intersection width W_i.

The delay incurred due to diversion is calculated by using Equation 18-37.

Equation 18-37

$$d_{pd,LOS} = 0.084 \frac{2D_d}{S_p} + d_{pc}$$

where

$d_{pd,LOS}$ = LOS-based pedestrian-perceived diversion delay (s/p),

D_d = diversion distance (ft),

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

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

The pedestrian delay incurred in crossing at the nearest signal-controlled crossing was determined in Step 3. If a midsegment crossing is illegal, then only diversion delay is used for the remainder of this step.

Exhibit has been given the number 20A to avoid renumbering subsequent exhibits, with possible cross-referencing ripple effects.

The LOS-based pedestrian-perceived diversion delay and the pedestrian waiting delay are each converted to an equivalent LOS score by using the thresholds listed in Exhibit 18-20A. Specifically, $d_{pd,LOS}$ is used with Exhibit 18-20A to determine the LOS score for diversion delay I_{pd}. Similarly, d_{pw} is used with Exhibit 18-20A to determine the LOS score for waiting delay I_{pw}. When either delay value is between the range limits shown in the table, interpolation is used to estimate the corresponding LOS score.

Exhibit 18-20A
LOS Scores Associated with Ranges of Midblock Pedestrian Delay

Delay Range (s)	Equivalent LOS Score Range
0 and ≤10	0 and ≤1.5
>10 and ≤20	>1.5 and ≤2.5
>20 and ≤30	>2.5 and ≤3.5
>30 and ≤40	>3.5 and ≤4.5
>40 and ≤60	>4.5 and ≤5.5
>60	>5.5

Finally, the midsegment crossing LOS score is computed using the following equation.

Equation 18-38

$$I_{p,mx} = \min[I_{pw}, I_{pd}, 6]$$

where

$I_{p,mx}$ = pedestrian LOS score for midsegment crossing (A = 1, B = 2, …, F = 6);

I_{pw} = LOS score for pedestrian waiting delay (based on Exhibit 18-20A); and

I_{pd} = LOS score for pedestrian diversion delay (based on Exhibit 18-20A).

Step 9: Determine Pedestrian LOS Score for Segment

The pedestrian LOS score for the segment is computed with Equation 18-39:

Equation 18-39

$$I_{p,seg} = \left[\frac{\left(I_{p,\text{link}}\,[1 - p_{mx}] + I_{p,mx}\,p_{mx}\right)^3 L/S_p + \left(I_{p,int}\right)^3 d_{pp}}{L/S_p + d_{pp}}\right]^{1/3}$$

where $I_{p,seg}$ is the pedestrian LOS score for the segment, p_{mx} is the proportion of pedestrian demand that desires to cross at a midsegment location (default: 0.35), and all other variables are as previously defined.

The segment LOS score is a weighted average of three separate LOS scores. As a result, it is likely to be less sensitive to a change in any one of the three separate LOS scores. In other words, the segment LOS score can mask important factors that are influencing link, intersection, or midsegment crossing LOS in isolation. For this reason, the HCM recommends that the analyst separately consider the link and intersection LOS scores individually to ensure that all factors influencing system performance are fully considered. This recommendation is extended to the analyst's consideration of the midsegment crossing LOS score.

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 18-2 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, LOS is determined by using Exhibit 18-3 because the pedestrian space concept does not apply.

5. BICYCLE METHODOLOGY

This section describes the methodology for evaluating the quality of service provided to bicyclists traveling along an urban street segment.

SCOPE OF THE METHODOLOGY

The overall scope of the four methodologies was provided in Section 2. This section identifies the additional conditions for which the bicycle methodology is applicable.

- *Target travel modes.* The bicycle methodology addresses travel by bicycle in the urban street right-of-way. It is not designed to evaluate the performance of other travel means (e.g., motorized bicycle, rickshaw).
- *Shared or exclusive lanes.* The bicycle methodology can be used to evaluate the service provided to bicyclists when they share a lane with motorized vehicles or when they travel in an exclusive bicycle lane.

Spatial Limits

Travel Directions to Be Evaluated

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 typical evaluation will focus on the performance of the segment (i.e., the link and boundary intersection combined). However, in some situations, an evaluation of just the link is appropriate. Each approach is discussed in this subsection.

Segment-Based Evaluation

For a segment-based evaluation, the bicycle methodology considers the performance of the link and the boundary intersection. It is applied through a series of eight steps that culminate in the determination of the segment LOS.

The methodology supports the analysis of a segment with either signal-controlled or two-way STOP-controlled boundary intersections. Chapter 19 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.

Link-Based Evaluation

Only two of the eight steps of the bicycle methodology are used 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 reflect all aspects of segment performance.

Performance Measures

Performance measures applicable to the bicycle travel mode include bicycle travel speed and bicycle LOS score. The LOS score is an indication of the typical bicyclist's perception of the overall segment travel experience.

LOS is also considered a performance measure. It is useful for describing segment performance to elected officials, policy makers, administrators, or the public. LOS is based on the bicyclist LOS score.

Limitations of the Methodology

This subsection identifies the known limitations of the bicycle methodology. If one or more of these limitations are believed to have an important influence on the performance of a specific street segment, the analyst should consider using alternative methods or tools for the evaluation.

The bicycle methodology does not account for the effect of the following conditions on the quality of service provided to bicyclists:

- Segments bounded by an all-way STOP-controlled intersection, roundabout, or signalized interchange ramp terminal;
- Grades in excess of 2%; and
- Presence of railroad crossings.

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the bicycle methodology. The required data are listed in Exhibit 18-21. They must be separately specified for each direction of travel on the segment and for each boundary intersection. The exhibit also lists default values that can be used if local data are not available (*2*, *3*).

Exhibit 18-21
Required Input Data, Potential Data Sources, and Default Values for Bicycle Analysis

Required Data and Units	Potential Data Source(s)	Suggested Default Value
	Traffic Characteristics	
Midsegment motorized vehicle flow rate[a] (veh/h)	Field data, past counts, forecasts	Must be provided
Heavy vehicle percentage (%)	Field data, past counts	Must be provided
Proportion of on-street parking occupied (decimal)	Field data	0.50 (if parking lane present)
	Geometric Design	
Segment length[a] (ft)	Field data, aerial photo	Must be provided
Number of midsegment through lanes[a]	Field data, aerial photo	Must be provided
Outside through lane width (ft)	Field data, aerial photo	12 ft
Bicycle lane width (ft)	Field data, aerial photo	5.0 ft (if provided)
Paved outside shoulder width (ft)	Field data, aerial photo	Must be provided
Striped parking lane width (ft)	Field data, aerial photo	Must be provided
Median type (divided or undivided)	Field data, aerial photo	Must be provided
Curb presence (yes or no)	Field data	Must be provided
Number of access point approaches	Field data, aerial photo	See discussion in text
	Other Data	
Pavement condition[b] (FHWA 5-point scale)	Field data, pavement condition inventory	3.5 (good)
	Performance Measures	
Motorized vehicle midsegment running speed[a] (mi/h)	HCM method output	Must be provided
Bicycle delay at boundary int. (s/bicycle)	HCM method output	Must be provided
Bicycle LOS score at boundary int. (decimal)	HCM method output	Must be provided

Notes: FHWA = Federal Highway Administration; int. = intersection.
Bold italic indicates high sensitivity (±2 LOS letters) of LOS to the choice of default value.
Bold indicates moderate sensitivity (±1 LOS letter) of LOS to the choice of default value.
[a] Also used or calculated by the motorized vehicle methodology.
[b] Sensitivity reflects pavement conditions 2–5. Very poor pavement (i.e., 1) typically results in LOS F, regardless of other input values.

The data elements listed in Exhibit 18-21 do not include variables that are considered to represent calibration factors. A calibration factor typically has a relatively narrow range of reasonable values or has 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.

Traffic Characteristics Data

This subsection describes the traffic characteristics data listed in Exhibit 18-21. These data describe the motorized vehicle and bicycle traffic streams traveling along the segment during the analysis period. Midsegment flow rate is defined in Section 3 for the motorized vehicle mode. The "proportion of on-street parking occupied" is defined in Section 4 for the pedestrian mode.

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* is 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.

Geometric Design Data

This subsection describes the geometric design data listed in Exhibit 18-21. These data describe the geometric elements that influence bicycle 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.

Most of the geometric design input data are defined in previous sections. Segment length, number of through lanes, and number of access point approaches are defined in Section 3 for the motorized vehicle mode. The following variables are defined in Section 4 for the pedestrian mode: width of outside through lane, width of bicycle lane, width of paved outside shoulder, width of striped parking lane, and curb presence.

Median type is designated as "undivided" or "divided." A street is indicated to have a divided median type if it has a nonrestrictive median (e.g., two-way left-turn lane) or restrictive (e.g., raised curb) median; otherwise, it is undivided.

Other Data

This subsection describes the data listed in Exhibit 18-21 that are categorized as "other data."

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 18-22 provides a description of pavement conditions associated with various ratings.

Exhibit 18-22
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

Performance Measures

This subsection describes the data listed in Exhibit 18-21 that are categorized as "performance measures."

Motorized Vehicle Running Speed

The motorized vehicle running speed is based on the segment running time obtained from the motorized vehicle methodology. The running speed is equal to the segment length divided by the segment running time.

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 Section 3 of Chapter 19 is used to compute this delay.

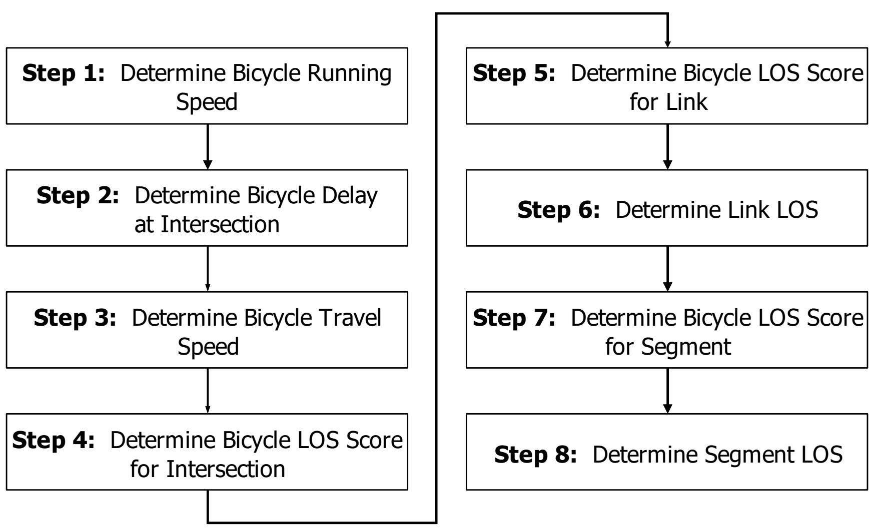
Bicycle LOS Score for Intersection

The bicycle LOS score for the signalized intersection is obtained from the bicycle methodology in Chapter 19.

OVERVIEW OF THE METHODOLOGY

This subsection provides an overview of the methodology for evaluating the performance of an urban street segment in terms of its service to bicyclists. The methodology consists of eight calculation steps. These steps are illustrated in Exhibit 18-23. All eight steps are completed for the typical segment-based evaluation. Only Steps 5 and 6 are needed for a link-based evaluation.

Exhibit 18-23
Bicycle Methodology for Urban Street Segments



A methodology for evaluating off-street bicycle facilities is provided in Chapter 24, Off-Street Pedestrian and Bicycle Facilities.

COMPUTATIONAL STEPS

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, the average running speed of bicycles is recommended to be taken as 15 mi/h between signalized intersections (*6*). 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), the delay is equal to 0.0 s/bicycle. If the boundary intersection is signalized, the delay is computed by using the motorized vehicle methodology described in Chapter 19, 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. Thus, it is typically slower than the average bicycle running speed. The average bicycle travel speed is computed by using Equation 18-40:

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

Equation 18-40

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, the bicycle methodology described in Chapter 19 is used for this determination. If the boundary intersection is two-way STOP controlled, the score is equal to 0.0.

Step 5: Determine Bicycle LOS Score for Link

The bicycle LOS score for the segment $I_{b,\text{link}}$ is calculated by using Equation 18-41:

Equation 18-41

$$I_{b,\text{link}} = 0.760 + F_w + F_v + F_s + F_p$$

with

Equation 18-42

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

Equation 18-43

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

Equation 18-44

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

Equation 18-45

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

where

- $I_{b,\text{link}}$ = 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 18-24) (ft),
- v_{ma} = adjusted midsegment demand flow rate (see Exhibit 18-24) (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 18-24) (mi/h),
- P_{HVa} = adjusted percent heavy vehicles in midsegment demand flow rate (see Exhibit 18-24) (%), and
- P_c = pavement condition rating (see Exhibit 18-22).

The value used for several of the variables in Equation 18-42 to Equation 18-45 is dependent on various conditions. These conditions are identified in Column 1 of Exhibit 18-24. If the condition is satisfied, the equation in Column 2 is used to compute the variable value. If it is not satisfied, 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 motorized vehicle methodology described in a previous subsection.

Exhibit 18-24
Variables for Bicycle LOS Score for Link

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

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_{pk} = width of striped parking lane (ft);
W_l = total width of shoulder, bicycle lane, and parking lane = $W_{bl} + W_{os}^* + W_{pk}$ (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 6: Determine Link LOS

The bicycle LOS for the link is determined by using the bicycle LOS score from Step 5. This score is compared with the link-based bicycle LOS thresholds in Exhibit 18-3 to determine the LOS for the specified direction of travel along the subject link.

Step 7: Determine Bicycle LOS Score for Segment

The bicycle LOS score for the segment is computed by using Equation 18-46:

Equation 18-46

$$I_{b,seg} = 0.75 \left[\frac{\left(F_c + I_{b,\text{link}} + 1\right)^3 t_{R,b} + \left(I_{b,int} + 1\right)^3 d_b}{t_{Rb} + d_b} \right]^{\frac{1}{3}} + 0.125$$

with

Equation 18-47

$$F_c = 0.035 \left(\frac{5{,}280\, N_{ap,s}}{L} - 20 \right)$$

where

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

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

F_c = unsignalized conflicts factor;

$I_{b,int}$ = 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 18-46 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 score is compared with the segment-based bicycle LOS thresholds in Exhibit 18-3 to determine the LOS for the specified direction of travel along the subject segment.

6. TRANSIT METHODOLOGY

This section describes the methodology for evaluating the capacity and quality of service provided to transit passengers on urban street segments.

SCOPE OF THE METHODOLOGY

The overall scope of the four methodologies was provided in Section 2. In addition, the transit methodology is limited to the evaluation of public transit vehicles operating in mixed or exclusive traffic lanes and stopping along the street. It is not designed to evaluate the performance of other travel means (e.g., grade-separated rail transit).

Spatial Limits

Travel Directions to Be Evaluated

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.*

Route-Based Evaluation

The methodology is used to evaluate a single transit route on the segment. If multiple routes exist on the segment, each route is evaluated by using a separate application of the methodology.

Performance Measures

Performance measures applicable to the transit travel mode include transit vehicle travel speed, transit wait–ride score, and transit LOS score. The LOS score is an indication of the typical transit rider's perception of the overall travel experience.

LOS is also considered a performance measure. It is useful for describing segment performance to elected officials, policy makers, administrators, or the public. LOS is based on the transit LOS score.

Limitations of the Methodology

In general, the methodology can be used to evaluate the performance of most urban street segments. However, it does not address all conditions or types of control. The inability to replicate the influence of a condition or control type in the methodology is a limitation.

This subsection identifies the known limitations of the transit methodology. If one or more of these limitations are believed to have an important influence on the performance of a specific street segment, the analyst should consider using alternative methods or tools for the evaluation.

The transit methodology does not account for the effect of the following conditions on the quality of service provided to transit passengers:

- Presence of railroad crossings, and
- Transit vehicles on grade-separated or non-public-street rights-of-way.

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* (*7*).

REQUIRED DATA AND SOURCES

This subsection describes the input data needed for the transit methodology. The required data are listed in Exhibit 18-25. They must be separately specified for each direction of travel on the segment and for each boundary intersection. The exhibit also lists default values that can be used if local data are not available (*2, 3*).

Exhibit 18-25
Required Input Data, Potential Data Sources, and Default Values for Transit Analysis

Required Data and Units	Potential Source(s)	Suggested Default Value
	Traffic Characteristics	
Dwell time (s)	Field data, AVL data	60 s (downtown stop, transit center, major on-line transfer point, major park-and-ride) 30 s (major outlying stop) 15 s (typical outlying stop)
Excess wait time (min)	Field data, AVL data	See discussion in text
Passenger trip length (mi)	National Transit Database	3.7 mi
Transit frequency (veh/h)	Transit schedules	Must be provided
Passenger load factor (p/seat)	Field data, APC data	0.80 p/seat
	Geometric Data	
Segment length[a] (ft)	Field data, aerial photo	Must be provided
	Other Data	
CBD of 5-million-plus metro area (yes/no)	Census data	Must be provided
Traffic signal effective green-to-cycle-length ratio (decimal)	Field data or HCM method output	Must be provided (if present)
Traffic signal cycle length (s)	Field data or HCM method output	Must be provided (if present)
Transit stop location (nearside/other)	Field data, aerial photo	Must be provided
Transit stop position (on-line/off-line)	Field data, aerial photo	Must be provided
Proportion of transit stops with shelters (decimal)	Field data, transit facility inventory	Must be provided
Proportion of transit stops with benches (decimal)	Field data, transit facility inventory	Must be provided
	Performance Measures	
Motorized vehicle running time[a] (s)	HCM method output	Must be provided
Pedestrian LOS score for link (decimal)	HCM method output	Must be provided
Reentry delay (s/veh)	HCM method output	Must be provided
Roundabout volume-to-capacity ratio (decimal)	HCM method output	Must be provided (if present)

Notes: AVL = automatic vehicle location, APC = automatic passenger counter, CBD = central business district.
[a] Also used or calculated by the motorized vehicle methodology.

The data elements listed in Exhibit 18-25 do not include variables that are considered to represent calibration factors. A calibration factor typically has a relatively narrow range of reasonable values or has 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.

Traffic Characteristics Data

This subsection describes the traffic characteristics data listed in Exhibit 18-25. These data describe the transit traffic streams traveling along the segment during the analysis period. If there are multiple transit routes on the segment, the transit-related variables are needed for each route.

Dwell Time

Dwell time is 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* (*7*).

Excess Wait Time

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, since 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, the methodology provides a procedure for estimating excess wait time from on-time performance.

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.

Passenger Trip Length

For most purposes, the average trip length can be determined from National Transit Database data for the transit agency (*8*) 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.

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.

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 is 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, 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.

Geometric Design Data

This subsection describes the geometric design data listed in Exhibit 18-25. These data describe the geometric elements that influence the service provided to transit passengers. 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 is the only variable in this category. It is defined in a similarly titled section for the motorized vehicle methodology.

Other Data

This subsection describes the data listed in Exhibit 18-25 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."

Effective Green-to-Cycle-Length Ratio and Cycle Length

The cycle length and the effective green-to-cycle-length ratio for the through movement are used in the transit methodology when the boundary intersection is a traffic signal. If the signal is actuated, the motorized vehicle methodology in Chapter 19 can be used to estimate the average green-to-cycle-length ratio and cycle length.

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 on 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 on exiting.

Proportion of Stops with Shelters and with Benches

These two input data elements describe the passenger amenities provided at a transit stop. A sheltered stop provides a structure with a roof and three enclosing 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 subsection describes the data listed in Exhibit 18-25 that are categorized as "performance measures."

Motorized Vehicle Running Time

The motorized vehicle running time for the segment is obtained from the motorized vehicle methodology that is described in Section 3.

Pedestrian LOS Score for Link

The pedestrian LOS score for the link is obtained from the pedestrian methodology that is described in Section 4.

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 (*7*):

- 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 20, 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 motorized vehicle methodology in Chapter 19, 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.

Volume-to-Capacity Ratio (If Roundabout)

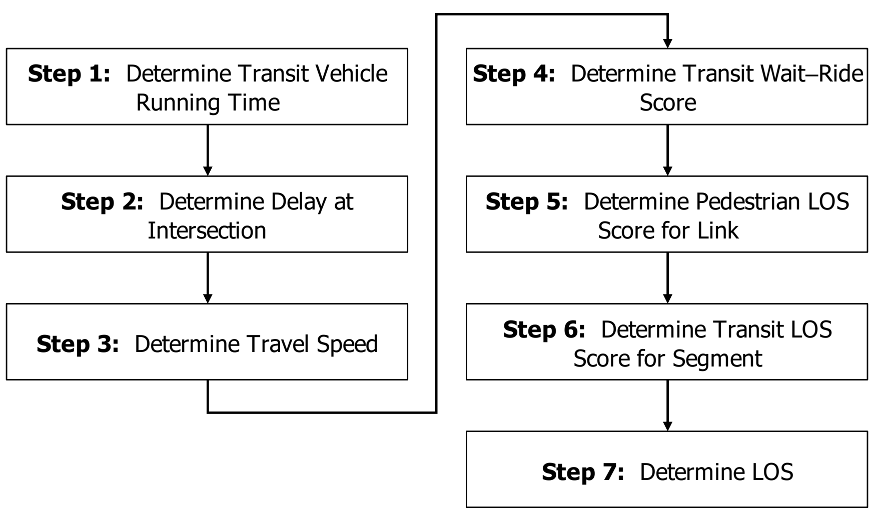
If the boundary intersection is a roundabout and it has a near-side transit stop, the volume-to-capacity ratio for the rightmost lane of the segment approach to the roundabout is needed. It is obtained from the Chapter 22 methodology.

OVERVIEW OF THE METHODOLOGY

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

The transit methodology is applied through a series of seven steps that culminate in the determination of segment LOS. These steps are illustrated in Exhibit 18-26. 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 18-26
Transit Methodology for Urban Street Segments



COMPUTATIONAL STEPS

Step 1: Determine Transit Vehicle Running Time

There are two principal components of the transit vehicle's segment running time. One is 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 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 subsection that describes the calculation of transit vehicle segment running time.

A. Compute Segment Running Speed

Transit vehicle segment running speed is the speed reached by the vehicle when it is not influenced by the proximity of a transit stop or traffic control device. This speed can be computed with Equation 18-48, which is derived from tables given in a Transit Cooperative Research Program report (*9*).

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

Equation 18-48

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 18-7 in Step 2 of the motorized vehicle 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 is the additional time required to decelerate to stop and then accelerate back to the transit vehicle running speed S_{Rt}. It is computed with Equation 18-49 and Equation 18-50.

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

Equation 18-49

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 18-50

where

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

r_{at} = transit vehicle acceleration rate = 3.3 (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 18-50 is used to determine the proportion of d_{ad} incurred solely because of a transit stop.

If representative acceleration and deceleration rates are known, they should be used in Equation 18-49. If these rates are unknown, an acceleration rate of 3.3 ft/s^2 and a deceleration rate of 4.0 ft/s^2 can be used (*7*).

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 18-51 is used to compute the delay due to serving passengers.

Equation 18-51

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

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 Data and Sources section.

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 with Equation 18-52.

Equation 18-52

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

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

C. Compute Segment Running Time

Equation 18-53 is used to compute transit vehicle running time, which is based on segment running speed and delay due to stops on the segment.

Equation 18-53

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

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

If there are no stops on the segment, the second term of Equation 18-53 equals zero.

Step 2: Determine Delay at Intersection

The through delay d_t incurred at the boundary intersection by the transit vehicle is determined in this step. This delay is equal to the control delay incurred by through vehicles that exit the segment at the downstream boundary intersection. Guidance for determining this delay is provided in Step 5 of the motorized vehicle methodology.

Alternatively, Equation 18-54 can be used to estimate the through delay due to a traffic signal (*9*). This estimate is suitable for a planning-level analysis.

Equation 18-54

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

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 18-54 is obtained from Exhibit 18-27.

Exhibit 18-27
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 (*9*).

Step 3: Determine Travel Speed

Transit travel speed is an aggregate measure of speed along the street. It combines the delay incurred at the downstream intersection with the segment running time. Thus, it is typically slower than the running speed. The transit travel speed is computed by using Equation 18-55.

Equation 18-55

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

where $S_{Tt,seg}$ is the travel speed of transit vehicles along the segment (mi/h), t_{Rt} is the segment running time of transit vehicles (s), and all 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, 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 subsections 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 18-56.

Equation 18-56

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

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 Data and Sources section.

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 with Equation 18-57.

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

Equation 18-57

with

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

Equation 18-58

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

Equation 18-59

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

Equation 18-60

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 typically (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 18-58. 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 amenities are provided at the transit stops.

The first term in Equation 18-58 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 18-58 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 18-58 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, Equation 18-61 may be used to estimate the average excess wait time.

Equation 18-61

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

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 18-58 represents the amenity time rate reduction. This rate is computed in Equation 18-60 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 (*8*). 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 with Equation 18-62. A larger score corresponds to better performance.

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

Equation 18-62

where

$s_{w\text{-}r}$ = 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 $I_{p,\text{link}}$ is computed by using the pedestrian methodology, as described in Section 4.

Step 6: Determine Transit LOS Score for Segment

The transit LOS score for the segment is computed by using Equation 18-63.

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

Equation 18-63

where $I_{t,seg}$ is the transit LOS score for the segment and all 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 18-3 to determine the LOS for the specified direction of travel along the subject street segment.

7. APPLICATIONS

EXAMPLE PROBLEMS

Chapter 30, Urban Street Segments: Supplemental, describes the application of each of the four methodologies through the use of example problems. There is one example problem associated with each methodology. The examples illustrate the operational analysis type.

GENERALIZED DAILY SERVICE VOLUMES

Generalized daily service volume tables provide a means of quickly assessing one or more urban street facilities to determine which facilities need to be more carefully evaluated (with operational analysis) to ameliorate existing or pending problems. Their application in practice is typically at the facility level rather than at the segment level. For this reason, service volume tables are provided in Chapter 16, Urban Street Facilities.

ANALYSIS TYPE

The four methodologies described in this chapter can each be used in three types of analysis. The analysis types are described as operational, design, and planning and preliminary engineering. The selected analysis type applies to the methodology described in this chapter and to all supporting methodologies. The characteristics of each analysis type are described in the subsequent paragraphs.

Operational Analysis

The objective of an operational analysis is to determine the LOS for current or near-term conditions when details of traffic volumes, geometry, and traffic control conditions are known. All the methodology steps are implemented and all calculation procedures are applied for the purpose of computing a wide range of performance measures. The operational analysis type will provide the most reliable results because it uses no (or minimal) default values.

Design Analysis

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.

The nature of the design analysis type depends 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 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 analysis type has two variations. Both variations require the specification of traffic conditions and target levels for a 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 analysis requires the additional specification of geometric conditions. The methodology is then applied by using an iterative approach in which alternative signalization conditions are evaluated.

Planning and Preliminary Engineering Analysis

The objective of a planning and preliminary engineering analysis can be (*a*) to determine the LOS for either a proposed segment or an existing segment in a future year or (*b*) 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 because 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 the section associated with each methodology.

The requirement for a complete description of the signal timing plan can be a burden for some planning analyses involving signalized intersections. The intersection planning-level analysis application 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 planning-level analysis application 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 subsection contains specific guidance for the application of alternative tools to the analysis of urban street segments. Additional information on this topic is provided in the Technical Reference Library in Volume 4. The focus of this subsection is the application of alternative tools to evaluate motorized vehicle operation.

Comparison of Motorized Vehicle Methodology and Alternative Tools

Motorized Vehicle Methodology

The motorized vehicle methodology models the driver–vehicle–road system with reasonable accuracy for most applications. It accounts for signal coordination, platoon dispersion, the origin–destination patterns of all segment traffic flows, driveway impacts on traffic flow, and the influence of volume on speed.

The motorized vehicle 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 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 several performance measures in a single application. Simulation tools require multiple runs and manual calculations to obtain an expected value for a given performance measure. A fourth is that its analytic procedures are described in the HCM so that analysts can understand the driver–vehicle–road interactions and the means by which they are modeled. Most proprietary alternative tools operate as a "black box," providing little detail describing the intermediate calculations.

Alternative Tools

Both deterministic tools and simulation tools are in common use as alternatives to the motorized vehicle methodology offered in this chapter. Deterministic tools are often used for the analysis of urban street segments. 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.

Conceptual Differences

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 of commonly defined performance measures.

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 Section 7 of Chapter 19.

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, comparability of platoon representation along a segment between these tools and the motorized vehicle methodology is difficult to achieve.

Alternative Tool Application Guidance

Development of HCM-Compatible Performance Measures

Alternative tools generally define 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 this chapter. Therefore, care must be taken in comparing speed and delay estimates from this chapter with those from other tools. Issues related to the comparison of speed (or delay) 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 definitions and procedures described in this chapter.

Adjustment of Parameters

For applications in which either an alternative tool or the motorized vehicle methodology can be used, some adjustment will generally be required for the alternative tool if consistency with the motorized vehicle 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 from the alternative tool match those estimated by the motorized vehicle methodology.

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

Sample Calculations Illustrating Alternative Tool Applications

Chapter 29, Urban Street Facilities: Supplemental, includes a set of examples illustrating the use of alternative tools to address the stated limitations of this chapter and Chapter 16, Urban Street Facilities. Specifically, the examples illustrate (*a*) the application of deterministic tools to optimize signal timing, (*b*) the effect of platooned arrivals at a roundabout, (*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.

8. REFERENCES

Some of these references can be found in the Technical Reference Library in Volume 4.

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