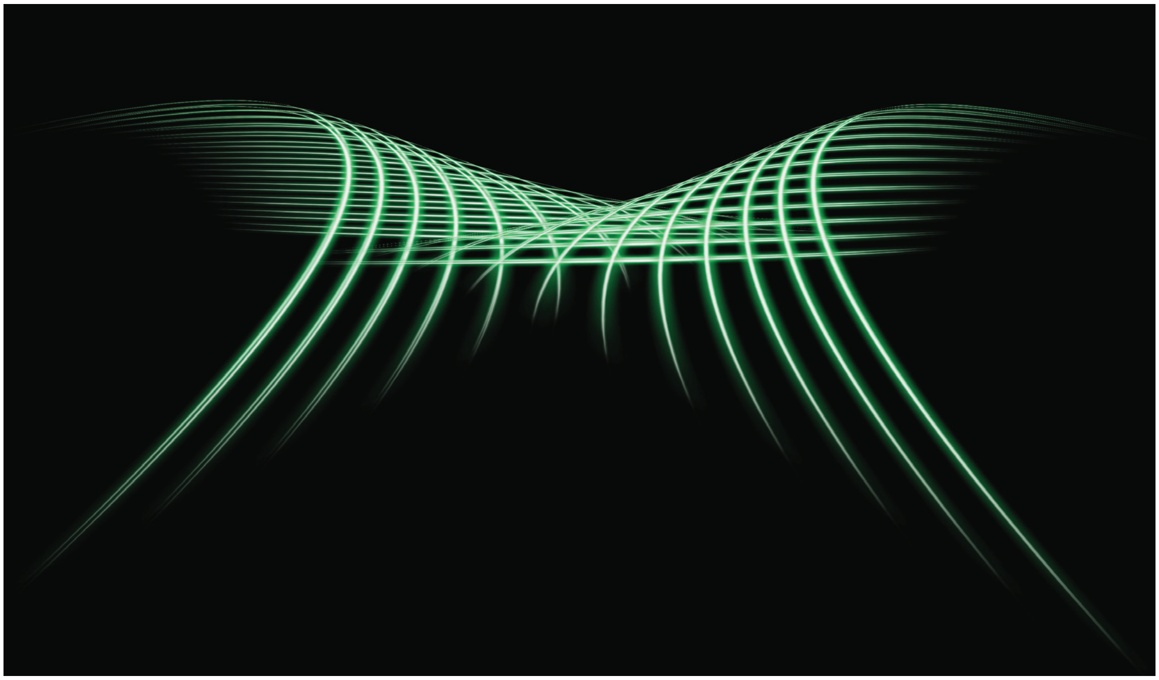
HCM2010

HIGHWAY CAPACITY MANUAL



CHAPTER 16

URBAN STREET FACILITIES

TRB TRANSPORTATION RESEARCH BOARD
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HCM2010

HIGHWAY CAPACITY MANUAL

The HCM 2010 significantly enhances how engineers and planners assess the traffic and environmental effects of highway projects by

- Providing an integrated multimodal approach to the analysis and evaluation of urban streets from the points of view of automobile drivers, transit passengers, bicyclists, and pedestrians;
- Addressing the proper application of microsimulation analysis and the evaluation of the results;
- Examining active traffic management in relation to demand and capacity; and
- Exploring specific tools and generalized service volume tables to assist planners in quickly sizing future facilities.

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Volume 3: Interrupted Flow; and
Volume 4: Applications Guide (electronic only).

The four-volume format provides information at several levels of detail, to help users more easily apply and understand the concepts, methodologies, and potential applications.

Volumes 1, 2, and 3 are issued as a boxed set. Volume 4 is electronic only, accessible to registered HCM users via the Internet, and includes four types of content: supplemental chapters on methodological details and emerging issues; interpretations, clarifications, and corrections; comprehensive case studies; and a technical reference library.

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CHAPTER 16
URBAN STREET FACILITIES

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

Chapter 16, Urban Street Facilities, describes an integrated multimodal methodology for evaluating the quality of service provided to road users traveling along an urban street. An urban street is unique among road types because it typically serves multiple travel modes. Four of the more common urban street travel modes include automobile, pedestrian, bicycle, and transit. Travelers associated with each of these modes use different criteria to evaluate the service provided to them when they travel along an urban street. This integrated multimodal approach allows analysts to analyze urban streets from a "complete streets" perspective.

Design or operational decisions that are intended to improve the service provided to one mode can sometimes have an adverse impact on the service provided to another mode. The challenge for the analyst is to design and operate the urban street in such a way that all relevant travel modes are reasonably accommodated. The methodology described in this chapter is intended to assist the analyst in this regard by providing a means to assess the performance of each urban street travel mode.

OVERVIEW OF THE METHODOLOGY

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

Analysis Level

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

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

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

Study Period and Analysis Period

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

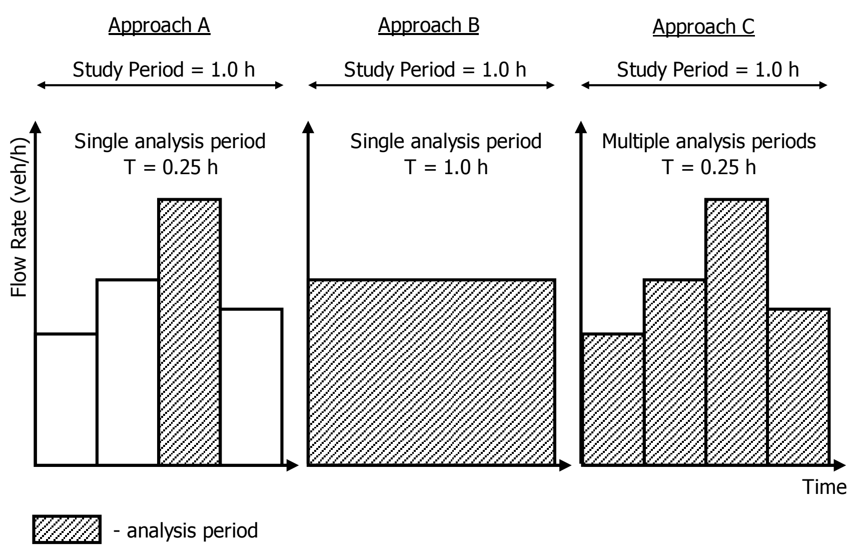
The methodology is based on the assumption that traffic conditions are steady during the analysis period (i.e., systematic change over time is negligible). For this reason, the duration of the analysis period is in the range of 0.25 to 1 h. The longer durations in this range are sometimes used for planning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

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

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

Exhibit 16-1 demonstrates three alternative approaches an analyst might use for a given evaluation. Note that other alternatives exist and that the study period can exceed 1 h. Approach A is the one that has traditionally been used and, unless otherwise justified, is the one that is recommended for use.

Exhibit 16-1
Three Alternative Study Approaches



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

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

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

Performance Measures

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

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

Travel Modes

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

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

Each methodology is focused on the evaluation of the urban street. A methodology for evaluating the segments that make up the street is described in Chapter 17, Urban Street Segments.

The four methodologies described in this chapter are based largely on the products of two National Cooperative Highway Research Program projects (*1*, *2*).

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

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

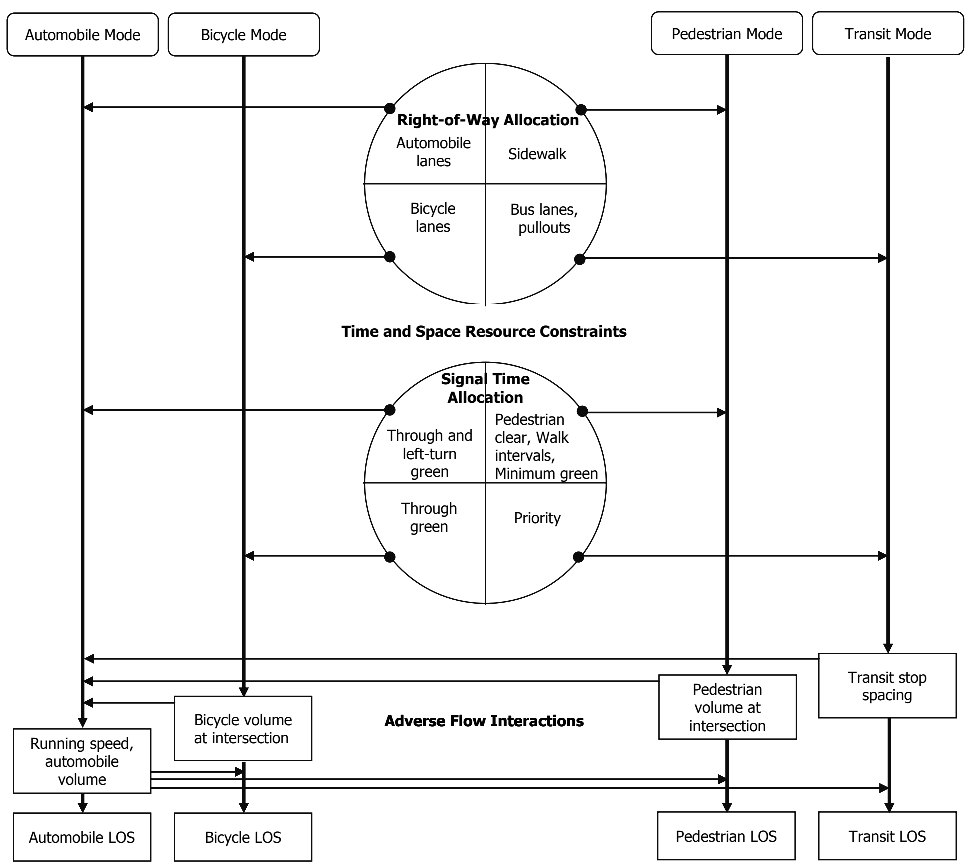
Multimodal Evaluation Framework

The urban street right-of-way is typically shared by multiple travel modes. Travelers associated with the more common modes include motorists, pedestrians, bicyclists, and transit passengers. The factors that influence the quality of service provided to these travelers vary by mode because each mode has a different trip purpose, length, and expectation.

The shared street right-of-way typically requires that the modes operate in close proximity to each other, sometimes even sharing the same portion of the cross section (e.g., a vehicular traffic lane). This arrangement may be workable when the modes are characterized by low demand volumes; however, acceptable operation for moderate to high volumes typically requires the spatial separation of the modes along the street and temporal (i.e., signal) separation at the intersections.

The integrated methodology described in Section 2 can be used to evaluate simultaneously the LOS provided to each travel mode on an urban street. A framework for this evaluation is shown in Exhibit 16-2.

Exhibit 16-2
Integrated Multimodal Evaluation Framework



The framework shown in Exhibit 16-2 illustrates the integrated multimodal evaluation approach supported by the methodology in Section 2. It is important to note that the LOS provided to each travel mode is separately evaluated. The relative importance given to each mode's LOS should be determined by the analyst (or operating agency) and reflect consideration of the subject street's functional class and purpose. The LOS for each mode should *not* be combined into one overall LOS for the street. This restriction recognizes that trip purpose, length, and expectation for each mode are different and that their combination does not produce a meaningful result.

Exhibit 16-2 illustrates how the travel modes compete for limited right-of-way along the street and at the intersections. They also compete for limited signal time at the intersections. For a given right-of-way, the allocation of space to one mode often requires a reduction (or elimination) of space for other modes and a corresponding reduction in their service quality.

The lower part of Exhibit 16-2 illustrates the potential adverse interactions between the automobile mode and the other modes. As the volume or speed of the automobile traffic stream increases, the LOS for the other modes may decrease. In contrast, if bicycle, pedestrian, or transit flows increase, then the LOS for the automobile traffic stream may decrease. In general, changes that alter resource allocation or flow interaction to improve the LOS for one mode may affect the other modes.

URBAN STREET FACILITY DEFINED

For the purpose of analysis, the urban street is separated into individual elements that are physically adjacent and operate as a single entity for the purpose of serving travelers. Two elements are commonly found on an urban street system: points and links. A *point* represents the boundary between links and is usually represented by an intersection or ramp terminal. A *link* represents a length of roadway between two points. A link and its boundary intersections are referred to as a *segment.* An urban street *facility* is a length of roadway that is composed of contiguous urban street segments and is typically functionally classified as an urban arterial or collector street.

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

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

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

Facility Length Considerations

Urban arterial and collector streets are designed to accommodate longer trips than local streets. They also have a significant mobility function and support the hierarchy of movement by connecting to streets of higher and lower functional class. An urban street facility with these attributes typically has a length of 1 mi or more in downtown areas and 2 mi or more in other areas. When an urban street facility meets or exceeds this length, average travel speed is a more meaningful indication of facility performance and LOS.

At least one intersection (or ramp terminal) along the facility must have a type of control that can impose on the through movement a legal requirement to stop or yield. A significant change in one or more facility characteristics may indicate the end of one facility and the start of a second facility. These characteristics include cross section features (e.g., number of through lanes, shoulder width, curb presence), annual average daily traffic volume, roadside development density and type, and vehicle speed. One or more of these characteristics will often change significantly when the street crosses an urban-to-suburban area boundary or intersects a freeway interchange.

If a facility assessment is desired for a given travel mode, the analyst will need to evaluate all of the segments that make up the facility for a common travel direction and aggregate the performance measures for each segment to obtain a facility performance estimate.

Facility Versus Segment Analysis Scope

The methodology described in Section 2 is used to evaluate an entire facility; however, for some specific conditions it may not be necessary to evaluate the entire facility. For these conditions, the appropriate segment or intersection chapter methodology may be used alone to evaluate selected segments or intersections. In general, it is up to the analyst to determine the scope of each analysis (i.e., one intersection, one segment, two segments, or all segments on the facility) on the basis of analysis objectives and agency directives.

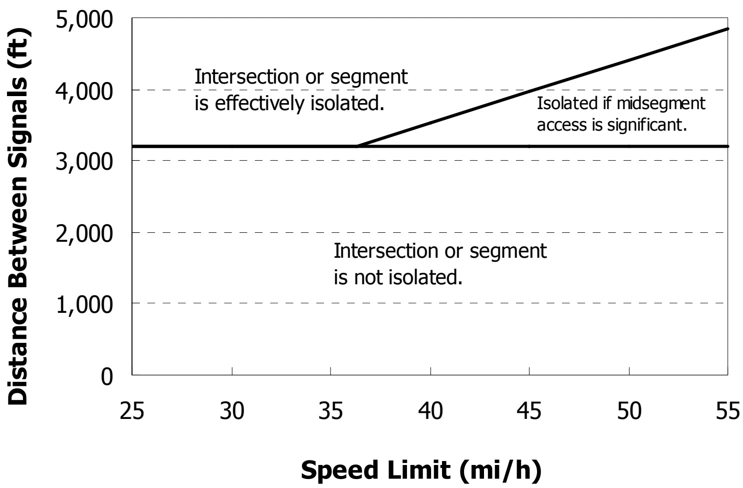
One condition for which it may be acceptable to evaluate an individual segment or intersection occurs when the segment or intersection is considered to operate in *isolation* from upstream signalized intersections. A segment or intersection that is effectively isolated experiences negligible influence from upstream signalized intersections. Flow on an isolated segment or at an isolated intersection is effectively random over the cycle and without a discernible platoon pattern evident in the cyclic profile of arrivals. These characteristics are more likely to be found when (*a*) the nearest upstream signalized intersection is sufficiently distant from the subject segment or intersection and (*b*) the subject segment or intersection, if signalized, is not coordinated with the upstream signal.

A segment or intersection is sufficiently distant from the nearest upstream signal if an intermediate intersection uses stop or yield control to regulate through traffic on the facility. If there is no intermediate STOP- or YIELD-controlled intersection, then Exhibit 16-3 can be used to obtain an indication of whether a segment or intersection is sufficiently distant from an upstream signal. If the distance between signals is above the trend line, then the subject intersection or segment is likely to operate as effectively isolated (provided that it is not coordinated with the upstream signal).

LOS CRITERIA

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

Exhibit 16-3
Signal Spacing Associated with Effectively Isolated Operation



Automobile Mode

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

Through-vehicle travel speed is used to characterize vehicular LOS for a given direction of travel along an urban street facility. This speed reflects the factors that influence running time along each link and the delay incurred by through vehicles at each boundary intersection. This performance measure indicates the degree of mobility provided by the facility. The following paragraphs characterize each service level.

LOS A describes primarily free-flow operation. Vehicles are completely unimpeded in their ability to maneuver within the traffic stream. Control delay at the boundary intersections is minimal. The travel speed exceeds 85% of the base free-flow speed.

LOS B describes reasonably unimpeded operation. The ability to maneuver within the traffic stream is only slightly restricted and control delay at the boundary intersections is not significant. The travel speed is between 67% and 85% of the base free-flow speed.

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 intersections may contribute to lower travel speeds. The travel speed is between 50% and 67% of the base free-flow speed.

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 intersections. The travel speed is between 40% and 50% of the base free-flow speed.

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 intersections. The travel speed is between 30% and 40% of the base free-flow speed.

LOS F is characterized by flow at extremely low speed. Congestion is likely occurring at the boundary intersections, as indicated by high delay and extensive queuing. The travel speed is 30% or less of the base free-flow speed. Also, LOS F is assigned to the subject direction of travel if the through movement at one or more boundary intersections has a volume-to-capacity ratio greater than 1.0.

Exhibit 16-4 lists the LOS thresholds established for the automobile mode on urban streets.

Exhibit 16-4
LOS Criteria: Automobile Mode

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

Note: [a] The critical volume-to-capacity ratio is based on consideration of the through movement volume-to-capacity ratio at each boundary intersection in the subject direction of travel. The critical volume-to-capacity ratio is the largest ratio of those considered.

Nonautomobile Modes

Historically, this manual has used a single performance measure as the basis for defining LOS. However, research documented in Chapter 5, Quality and Level-of-Service Concepts, indicates that travelers consider a wide variety of factors 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 in Chapter 17, Urban Street Segments, and Chapter 18, Signalized Intersections, provide procedures for mathematically combining these factors into a score for the segment or intersection, respectively. This score is then used in this chapter to determine the LOS that is provided for a given direction of travel along a facility.

Exhibit 16-5 lists the range of scores associated with each LOS for the pedestrian travel mode. The LOS for this particular mode is determined by consideration of both the LOS score and the average pedestrian space on the sidewalk. The applicable LOS for an evaluation is determined from the table by finding the intersection of the row corresponding to the computed score value and the column corresponding to the computed space value.

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 respondents to identify the best and worst conditions on the basis of their traveling experience and perception of service quality.

Exhibit 16-5
LOS Criteria: Pedestrian Mode

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

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

Exhibit 16-6 lists the range of scores that are associated with each LOS for the bicycle and transit modes. This exhibit is also applicable for determining pedestrian LOS when a sidewalk is not available.

Exhibit 16-6
LOS Criteria: Bicycle and Transit Modes

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

REQUIRED INPUT DATA

This subsection describes the required input data for the automobile, pedestrian, bicycle, and transit methodologies.

Automobile Mode

This part describes the input data needed for the automobile methodology. The data are listed in Exhibit 16-7 and are identified as "input data elements." For the subject travel direction, these elements must be provided for each segment and for the through-movement group at each boundary intersection.

The last column in Exhibit 16-7 indicates whether the input data are needed for a movement group at a boundary intersection, the overall intersection, or the segment. The input data needed to evaluate the segment are identified in Chapter 17, Urban Street Segments. Similarly, the input data needed to evaluate the boundary intersections are identified in the appropriate chapter (i.e., Chapters 18 to 22).

Exhibit 16-7
Input Data Requirements: Automobile Mode

Data Category	Location	Input Data Element	Basis
Geometric Design	Segment	Segment length	Segment
Other	Segment	Analysis period duration	Facility
Performance Measures	Boundary intersection	Volume-to-capacity ratio	Through-movement group
	Segment	Base free-flow speed Travel speed	Segment Segment

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

Segment Length

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

Analysis Period Duration

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

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

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

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

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

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

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

Volume-to-Capacity Ratio

This volume-to-capacity ratio is for the lane group serving the through movement that exits the segment at the downstream boundary intersection. With one exception, a procedure for computing this ratio is described in the appropriate intersection chapter (i.e., Chapters 18 to 22). Chapter 19, Two-Way STOP-Controlled Intersections, does not provide a procedure for estimating the capacity of the uncontrolled through movement, but this capacity can be estimated by using Equation 16-1:

Equation 16-1

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

where

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

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

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

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

One volume-to-capacity ratio is needed for the downstream boundary intersection of each segment on the facility.

Base Free-Flow Speed

The base free-flow speed characterizes the traffic speed on the segment when free-flow conditions exist and speed is uninfluenced by signal spacing. A procedure for determining this speed is described in Chapter 17. One speed is needed for each travel direction on each segment on the facility.

Travel Speed

Travel speed represents the ratio of segment length to through-movement travel time. Travel time is computed as the sum of segment running time and through-movement control delay at the downstream boundary intersection. A procedure for computing travel speed is described in Chapter 17. One speed is needed for each travel direction of each segment on the facility.

Nonautomobile Modes

This part describes the input data needed for the pedestrian, bicycle, and transit methodologies. The data are listed in Exhibit 16-8 and are identified as "input data elements." They must be separately specified for each direction of travel on the facility. Segment length is defined in the previous part.

Exhibit 16-8 categorizes each input data element by travel mode methodology. An "X" is used to indicate the association between a data element and methodology. A blank cell indicates that the data element is not used as input for the corresponding methodology.

Exhibit 16-8
Input Data Requirements: Nonautomobile Modes

Data Category	Location	Input Data Element	Pedestrian Mode	Bicycle Mode	Transit Mode
Geometric Design	Segment	Segment length	X	X	X
		Presence of a sidewalk	X		
Performance Measures	Segment	Pedestrian space	X		
		Pedestrian travel speed	X		
		Pedestrian LOS score for segment	X		
		Bicycle travel speed		X	
		Bicycle LOS score for segment		X	
		Transit travel speed			X
		Transit LOS score for segment			X

Presence of a Sidewalk

A sidewalk is a paved walkway that is provided at the side of the roadway. It is assumed that pedestrians will walk in the street if a sidewalk is not present. An indication of sidewalk presence is needed for each side of interest for each segment on the facility.

Pedestrian Space

Pedestrian space is a performance measure that describes the average circulation area available to each pedestrian traveling along the sidewalk. A procedure is described in Chapter 17 for estimating this quantity for a given sidewalk. One value is needed for each sidewalk of interest associated with each segment on the facility.

Pedestrian Travel Speed

Pedestrian travel speed represents the ratio of segment length to pedestrian travel time. Travel time is computed as the sum of segment walking time and control delay at the downstream boundary intersection. A procedure for computing this travel speed is described in Chapter 17. One speed is needed for each sidewalk of interest associated with each segment on the facility.

Pedestrian LOS Score for Segment

The pedestrian LOS score for the segment is used in the pedestrian methodology to determine facility LOS. It is obtained from the pedestrian methodology in Chapter 17. One score is needed for each direction of travel of interest for each segment on the facility.

Bicycle Travel Speed

Bicycle travel speed represents the ratio of segment length to bicycle travel time. Travel time is computed as the sum of segment running time and control delay at the downstream boundary intersection. This speed is computed only when a bicycle lane is present on the segment. A procedure for computing this travel speed is described in Chapter 17. One speed is needed for each direction of travel of interest for each segment on the facility.

Bicycle LOS Score for Segment

The bicycle LOS score for the segment is used in the bicycle methodology to estimate facility LOS. It is obtained from the bicycle methodology in Chapter 17. One score is needed for each direction of travel of interest for each segment on the facility.

Transit Travel Speed

Transit travel speed represents the ratio of segment length to transit travel time. Travel time is computed as the sum of segment running time and control delay at the downstream boundary intersection. A procedure for computing this travel speed is described in Chapter 17. One speed is needed for each direction of travel of interest for each segment on the facility.

Transit LOS Score for Segment

The transit LOS score for the segment is used in the transit methodology to estimate facility LOS. It is obtained from the transit methodology in Chapter 17. One score is needed for each direction of travel of interest for each segment on the facility.

SCOPE OF THE METHODOLOGY

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

- **Signalized and two-way STOP-controlled boundary intersections.** All methodologies can be used to evaluate facility performance with signalized or two-way STOP-controlled boundary intersections. In the latter case, the cross street is STOP controlled. The automobile methodology can also be used to evaluate performance with all-way STOP- or YIELD-controlled (e.g., roundabout) boundary intersections.
- **Arterial and collector streets.** The four methodologies were developed with a focus on arterial and collector street conditions. If a methodology is used to evaluate a local street, then the performance estimates should be carefully reviewed for accuracy.
- **Steady flow conditions.** The four methodologies are based on the analysis of steady traffic conditions and, as such, are not well suited to the

evaluation of unsteady conditions (e.g., congestion, queue spillback, signal preemption).

- **Target road users.** Collectively, the four methodologies were developed to estimate the LOS perceived by automobile drivers, pedestrians, bicyclists, and transit passengers. They were not developed to provide an estimate of the LOS perceived by other road users (e.g., commercial vehicle drivers, automobile passengers, delivery truck drivers, or recreational vehicle drivers). However, it is likely that the perceptions of these other road users are reasonably well represented by the road users for whom the methodologies were developed.
- **Target travel modes.** The automobile methodology addresses mixed automobile, motorcycle, truck, and transit traffic streams in which the automobile represents the largest percentage of all vehicles. The pedestrian, bicycle, and transit methodologies address travel by walking, bicycle, and transit vehicle, respectively. The transit methodology is limited to the evaluation of public transit vehicles operating in mixed or exclusive traffic lanes and stopping along the street. The methodologies are not designed to evaluate the performance of other travel means (e.g., grade-separated rail transit, golf carts, or motorized bicycles).
- **Influences in the right-of-way.** A road user's perception of quality of service is influenced by many factors inside and outside of the urban street right-of-way. However, the methodologies in this chapter were specifically constructed to exclude factors that are outside of the right-of-way (e.g., buildings, parking lots, scenery, or landscaped yards) that might influence a traveler's perspective. This approach was followed because factors outside of the right-of-way are not under the direct control of the agency operating the street.
- **Mobility focus for automobile methodology.** The automobile methodology is intended to facilitate the evaluation of mobility. Accessibility to adjacent properties by way of automobile is not directly evaluated with this methodology. Regardless, a segment's accessibility should also be considered when its performance is evaluated, especially if the street is intended to provide such access. Oftentimes, factors that favor mobility reflect minimal levels of access and vice versa.
- **"Typical pedestrian" focus for pedestrian methodology.** The pedestrian methodology is not designed to reflect the perceptions of any particular pedestrian subgroup, such as pedestrians with disabilities. As such, the performance measures obtained from the methodology are not intended to be indicators of a sidewalk's compliance with U.S. Access Board guidelines related to the Americans with Disabilities Act requirements. For this reason, they should not be considered as a substitute for a formal compliance assessment of a pedestrian facility.

LIMITATIONS OF THE METHODOLOGY

The urban street facility methodology uses the performance measures estimated by the segment and intersection methodologies in Chapters 17 to 22. As such, it incorporates the limitations of these methodologies (which are identified in the respective segment or intersection chapter).

2. METHODOLOGY

OVERVIEW

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

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

The focus of each methodology in this chapter is the facility. Methodologies for quantifying the performance of a segment or boundary intersection are described in other chapters (i.e., Chapters 17 to 22).

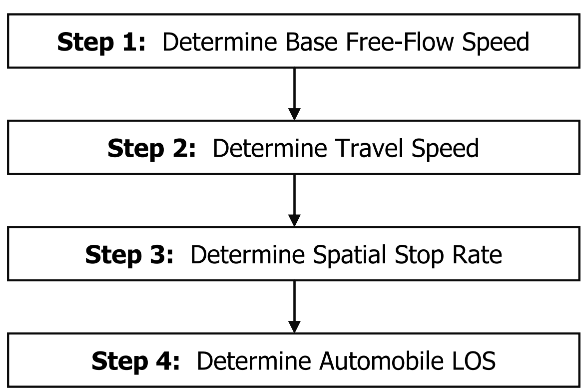
AUTOMOBILE MODE

This subsection provides an overview of the methodology for evaluating urban street facility performance from the motorist perspective. Each travel direction along the facility is separately evaluated. *Unless otherwise stated, all variables are specific to the subject direction of travel.*

The methodology is focused on the analysis of facilities with signalized, two-way STOP, all-way STOP, or roundabout boundary intersections. The signalized intersection can be an interchange ramp terminal.

Exhibit 16-9 illustrates the calculation framework of the automobile methodology. It identifies the sequence of calculations needed to estimate selected performance measures. The calculation process is shown to flow from top to bottom in the exhibit. The calculations are described more fully in the remainder of this subsection.

Exhibit 16-9
Automobile Methodology for Urban Street Facilities



Step 1: Determine Base Free-Flow Speed

The base free-flow speed for the facility is the basis for LOS determination. It is determined for each segment by using the procedures described in Chapter 17, Urban Street Segments. The base free-flow speed for the facility is calculated by using Equation 16-2:

Equation 16-2

$$S_{fo,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{fo,i}}}$$

where

$S_{fo,F}$ = base free-flow speed for the facility (mi/h),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$S_{fo,i}$ = base free-flow speed for segment i (mi/h).

Step 2: Determine Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed for the through-vehicle traffic stream that reflects the running speed along the street for through vehicles and any delay they may incur at the boundary intersections. The travel speed for through vehicles is determined for each segment by using the procedures described in Chapter 17. The travel speed for the facility is calculated by using Equation 16-3:

Equation 16-3

$$S_{T,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{T,seg,i}}}$$

where $S_{T,F}$ is the travel speed for the facility (mi/h), $S_{T,seg,i}$ is the travel speed of through vehicles for segment i (mi/h), and other variables are as previously defined.

Step 3: Determine Spatial Stop Rate

The spatial stop rate for the facility is the ratio of stop count to facility length. It relates the number of full stops incurred by the average through vehicle to the distance traveled. The spatial stop rate for through vehicles is determined for each segment by using the procedures described in Chapter 17. The spatial stop rate for the facility is calculated by using Equation 16-4:

Equation 16-4

$$H_F = \frac{\sum_{i=1}^{m} H_{seg,i}\ L_i}{\sum_{i=1}^{m} L_i}$$

where H_F is the spatial stop rate for the facility (stops/mi), $H_{seg,i}$ is the spatial stop rate for segment i (stops/mi), and other variables are as previously defined.

The spatial stop rate from Equation 16-4 can be used to estimate an automobile traveler perception score for the facility if desired. The equations in Step 10 of Chapter 17 are used for this purpose. The value of H_F would be substituted for H_{seg} in each equation. Similarly, the proportion of intersections with a left-turn lane P_{LTL} would be calculated for the entire facility and this one value used in each equation.

Step 4: Determine Automobile LOS

LOS is determined for both directions of travel along the facility. Exhibit 16-4 lists the LOS thresholds established for this purpose. As indicated in this exhibit, LOS is defined by travel speed, expressed as a percentage of the base free-flow speed. The base free-flow speed is computed in Step 1 and the travel speed is computed in Step 2.

The footnote to Exhibit 16-4 indicates that volume-to-capacity ratio for the through movement at the downstream boundary intersections is also relevant to the determination of facility LOS. This footnote indicates that LOS F is assigned to the subject direction of travel if a volume-to-capacity ratio greater than 1.0 exists for the through movement at one or more boundary intersections.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

PEDESTRIAN MODE

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

Urban street facility 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.*

The methodology is focused on the analysis of facilities with either signal-controlled or two-way STOP-controlled boundary intersections. This edition of the HCM does not include a procedure for evaluating a facility's performance when a boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The pedestrian methodology is applied through a series of four steps that culminate in the determination of the facility LOS. These steps are illustrated in Exhibit 16-10.

Exhibit 16-10
Pedestrian Methodology for Urban Street Facilities

Step 1: Determine Pedestrian Space
↓
Step 2: Determine Pedestrian Travel Speed
↓
Step 3: Determine Pedestrian LOS Score
↓
Step 4: Determine Pedestrian LOS

Concepts

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

A third measure is based on the concept of "circulation area." It represents the average amount of sidewalk area available to each pedestrian walking along the facility. A larger area is more desirable from the pedestrian perspective. Exhibit 16-11 provides a qualitative description of pedestrian space that can be used to evaluate sidewalk performance from a circulation-area perspective.

Exhibit 16-11
Qualitative Description of Pedestrian Space

Pedestrian Space (ft^2/p)		
Random Flow	**Platoon Flow**	**Description**
>60	>530	Ability to move in desired path, no need to alter movements
>40–60	>90–530	Occasional need to adjust path to avoid conflicts
>24–40	>40–90	Frequent need to adjust path to avoid conflicts
>15–24	>23–40	Speed and ability to pass slower pedestrians restricted
>8–15	>11–23	Speed restricted, very limited ability to pass slower pedestrians
≤ 8	≤ 11	Speed severely restricted, frequent contact with other users

The first two columns in Exhibit 16-11 indicate a sensitivity to flow condition. Random pedestrian flow is typical of most facilities. Platoon flow is appropriate for facilities made up of shorter segments (e.g., in downtown areas) with signalized boundary intersections.

Step 1: Determine 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 facility performance for travel in a sidewalk. This step is applicable only when the sidewalk exists on the subject side of the street.

The pedestrian space is determined for each segment by using the procedures described in Chapter 17, Urban Street Segments. The pedestrian space for the facility is calculated by using Equation 16-5:

Equation 16-5

$$A_{p,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{A_{p,i}}}$$

where

$A_{p,F}$ = pedestrian space for the facility (ft²/p),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$A_{p,i}$ = pedestrian space for segment i (ft²/p).

The pedestrian space for the facility reflects the space provided on the sidewalk along the segment. It does not consider the corner circulation area or the crosswalk circulation area at the intersections. Regardless, the analyst should verify that the intersection corners and crosswalks adequately accommodate pedestrians.

Step 2: Determine Pedestrian Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed of pedestrians that reflects their walking speed along the sidewalk and any delay they may incur at the boundary intersections. The travel speed for pedestrians is determined for each segment by using the procedures described in Chapter 17. The pedestrian travel speed for the facility is calculated by using Equation 16-6:

Equation 16-6

$$S_{Tp,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{Tp,seg,i}}}$$

where $S_{Tp,F}$ is the travel speed of through pedestrians for the facility (ft/s), $S_{Tp,seg,i}$ is the travel speed of through pedestrians for segment i (ft/s), and other variables are as previously defined.

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 3: Determine Pedestrian LOS Score

The pedestrian LOS score for the facility is computed in this step. It represents a length-weighted average of the pedestrian LOS scores for the individual segments that make up the facility. The segment scores are determined by using the procedures described in Chapter 17. The score for the facility is calculated by using Equation 16-7:

$$I_{p,F} = \frac{\sum_{i=1}^{m} I_{p,seg,i}\ L_i}{\sum_{i=1}^{m} L_i}$$

Equation 16-7

where

$I_{p,F}$ = pedestrian LOS score for the facility, and

$I_{p,seg,i}$ = pedestrian LOS score for segment *i*.

Other variables are as previously defined.

Step 4: Determine Pedestrian LOS

The pedestrian LOS for the facility is determined by using the pedestrian LOS score from Step 3 and the average pedestrian space from Step 1. These two performance measures are compared with their respective thresholds in Exhibit 16-5 to determine the LOS for the specified direction of travel along the subject facility. If the sidewalk does not exist and pedestrians are relegated to walking in the street, then LOS is determined by using Exhibit 16-6 because the pedestrian space concept does not apply.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

BICYCLE MODE

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

Urban street facility 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 methodology is focused on the analysis of a facility with either signal-controlled or two-way STOP-controlled boundary intersections. This edition of the HCM does not include a procedure for evaluating a facility's performance when a boundary intersection is an all-way STOP-controlled intersection, a roundabout, or a signalized interchange ramp terminal.

The bicycle methodology is applied through a series of three steps that culminate in the determination of the facility LOS. These steps are illustrated in Exhibit 16-12.

Exhibit 16-12
Bicycle Methodology for Urban Street Facilities

Step 1: Determine Bicycle Travel Speed

↓

Step 2: Determine Bicycle LOS Score

↓

Step 3: Determine Bicycle LOS

Step 1: Determine Bicycle Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed of bicycles that reflects their running speed along the street and any delay they may incur at the boundary intersections. The travel speed for bicycles is determined for each segment by using the procedures described in Chapter 17. The bicycle travel speed for the facility is calculated by using Equation 16-8:

Equation 16-8

$$S_{Tb,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{Tb,seg,i}}}$$

where

$S_{Tb,F}$ = travel speed of through bicycles for the facility (mi/h),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$S_{Tb,seg,i}$ = travel speed of through bicycles for segment i (mi/h).

Step 2: Determine Bicycle LOS Score

The bicycle LOS score for the facility is computed in this step. It represents a length-weighted average of the bicycle LOS scores for the individual segments that make up the facility. The segment scores are determined by using the procedures described in Chapter 17. The score for the facility is calculated by using Equation 16-9:

Equation 16-9

$$I_{b,F} = \frac{\sum_{i=1}^{m} I_{b,seg,i}\ L_i}{\sum_{i=1}^{m} L_i}$$

where $I_{b,F}$ is the bicycle LOS score for the facility, $I_{b,seg,i}$ is the bicycle LOS score for segment i, and other variables are as previously defined.

Step 3: Determine Bicycle LOS

The bicycle LOS for the facility is determined by using the bicycle LOS score from Step 2. This performance measure is compared with the thresholds in Exhibit 16-6 to determine the LOS for the specified direction of travel along the subject facility.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

TRANSIT MODE

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

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

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

The transit methodology is applied through a series of three steps that culminate in the determination of facility LOS. These steps are illustrated in Exhibit 16-13. If multiple routes exist on the segment, then each route is evaluated by using a separate application of this methodology.

Exhibit 16-13
Transit Methodology for Urban Street Facilities

Step 1: Determine Transit Travel Speed

↓

Step 2: Determine Transit LOS Score

↓

Step 3: Determine Transit LOS

Step 1: Determine Transit Travel Speed

The travel speed for the facility is the ratio of facility length to facility travel time. It represents an equivalent average speed of transit vehicles that reflects their running speed along the street and any delay they may incur at the boundary intersection. The travel speed for a transit vehicle is determined for each segment by using the procedures described in Chapter 17. The transit travel speed for the facility is calculated by using Equation 16-10:

Equation 16-10

$$S_{Tt,F} = \frac{\sum_{i=1}^{m} L_i}{\sum_{i=1}^{m} \frac{L_i}{S_{Tt,seg,i}}}$$

where

$S_{Tt,F}$ = travel speed of transit vehicles for the facility (mi/h),

L_i = length of segment i (ft),

m = number of segments on the facility, and

$S_{Tt,seg,i}$ = travel speed of transit vehicles for segment i (mi/h).

Step 2: Determine Transit LOS Score

The transit LOS score for the facility is computed in this step. It represents a length-weighted average of the transit LOS score for the individual segments that make up the facility. The segment scores are determined by using the procedures described in Chapter 17. The score for the facility is calculated by using Equation 16-11:

Equation 16-11

$$I_{t,F} = \frac{\sum_{i=1}^{m} I_{t,seg,i}\, L_i}{\sum_{i=1}^{m} L_i}$$

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

Step 3: Determine Transit LOS

The transit LOS for the facility is determined by using the transit LOS score from Step 2. This performance measure is compared with the thresholds in Exhibit 16-6 to determine the LOS for the specified direction of travel along the subject facility.

Facility LOS must be interpreted with caution. It can suggest acceptable operation of the facility when, in reality, certain segments are operating at an unacceptable LOS. For each travel direction, the analyst should always verify that each segment is providing acceptable operation and consider reporting the LOS for the poorest-performing segment as a means of providing context for the interpretation of facility LOS.

3. APPLICATIONS

TYPES OF ANALYSIS

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

Operational Analysis

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

Design Analysis

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

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

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

Planning and Preliminary Engineering Analysis

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

The level of precision inherent in planning and preliminary engineering analyses is typically lower than for operational analyses. Therefore, default values are often substituted for field-measured values of many of the input variables. Recommended default values for this purpose are provided in Chapters 17 to 22.

USE OF ALTERNATIVE TOOLS

Chapter 29, Urban Street Facilities: Supplemental, includes a set of examples to illustrate the use of alternative tools to address the stated limitations of this chapter and Chapter 17, Urban Street Segments. Specifically, these examples are used to illustrate (*a*) the application of deterministic tools to optimize the signal timing, (*b*) the effect of using a roundabout as a segment boundary, (*c*) the effect of midsegment parking maneuvers on facility operation, and (*d*) the use of simulated vehicle trajectories to evaluate the proportion of time that the back of the queue on the minor-street approach to a two-way STOP-controlled intersection exceeds a specified distance from the stop line.

GENERALIZED DAILY SERVICE VOLUMES FOR URBAN STREET FACILITIES

Generalized daily service volume tables provide a means to assess a large number of urban streets in a region or jurisdiction quickly to determine which facilities need to be assessed more carefully (by using operational analysis) to ameliorate existing or pending problems.

To build a generalized daily service volume table for urban street facilities, a number of simplifying assumptions must be made. The assumptions made here include the following:

- All segments of the facility have the same number of through lanes (one, two, or three) in each direction;
- Only traffic signal control is used along the facility (i.e., no roundabouts or all-way STOP-controlled intersections exist);
- The traffic signals are coordinated and semi-actuated, the arrival type is 4, the traffic signal cycle time C is 120 s, and the weighted average green-to-cycle-length (g/C) ratio for through movements (defined below) is 0.45;
- Exclusive left-turn lanes with protected left-turn phasing and adequate queue storage are provided at each signalized intersection, and no exclusive right-turn lanes are provided;
- At each traffic signal, 10% of the traffic on the urban street facility turns left and 10% turns right;
- The peak hour factor is 0.92;
- The facility length is 2 mi, and no restrictive medians exist along the facility; and
- The base saturation flow rate s_o is 1,900 passenger cars per hour per lane (pc/h/ln).

The weighted average g/C ratio of an urban street is the average of the critical intersection through g/C ratio and the average of all the other g/C ratios for the urban street. For example, if there are four signals with a through g/C ratio of 0.50 and one signal with a through g/C ratio of 0.40, the weighted average g/C ratio for the urban street is 0.45. The weighted g/C ratio takes into account the adverse effect of the critical intersection and the overall quality of flow for the urban street.

Generalized daily service volumes are provided in Exhibit 16-14 for urban street facilities with posted speeds of 30 and 45 mi/h; two, four, or six lanes (both directions); and six combinations of the K-factor and D-factor. To use this table, analysts must select a combination of K and D appropriate for their locality.

The 30-mi/h values further assume an average traffic signal spacing of 1,050 ft and 20 access points/mi, while the 45-mi/h values assume an average traffic signal spacing of 1,500 ft and 10 access points/mi.

Exhibit 16-14
Generalized Daily Service Volumes for Urban Street Facilities (1,000 veh/day)

K-Factor	*D*-Factor	Two-Lane Streets LOS B	LOS C	LOS D	LOS E	Four-Lane Streets LOS B	LOS C	LOS D	LOS E	Six-Lane Streets LOS B	LOS C	LOS D	LOS E
Posted Speed = 30 mi/h													
0.09	0.55	NA	5.9	15.4	19.9	NA	11.3	31.4	37.9	NA	16.3	46.4	54.3
	0.60	NA	5.4	14.1	18.3	NA	10.3	28.8	34.8	NA	15.0	42.5	49.8
0.10	0.55	NA	5.3	13.8	17.9	NA	10.1	28.2	34.1	NA	14.7	41.8	48.9
	0.60	NA	4.8	12.7	16.4	NA	9.3	25.9	31.3	NA	13.5	38.3	44.8
0.11	0.55	NA	4.8	12.6	16.3	NA	9.2	25.7	31.0	NA	13.4	38.0	44.5
	0.60	NA	4.4	11.5	14.9	NA	8.4	23.5	28.4	NA	12.2	34.8	40.8
Posted Speed = 45 mi/h													
0.09	0.55	NA	10.3	18.6	19.9	NA	21.4	37.2	37.9	NA	31.9	54.0	54.3
	0.60	NA	9.4	17.1	18.3	NA	19.6	34.1	34.8	NA	29.2	49.5	49.8
0.10	0.55	NA	9.3	16.8	17.9	NA	19.3	33.5	34.1	NA	28.7	48.6	48.9
	0.60	NA	8.5	15.4	16.4	NA	17.7	30.7	31.3	NA	26.3	44.5	44.8
0.11	0.55	NA	8.4	15.3	16.3	NA	17.5	30.5	31.0	NA	26.1	44.2	44.4
	0.60	NA	7.7	14.0	14.9	NA	16.1	27.9	28.4	NA	23.9	40.5	40.7

Notes: NA = not applicable; LOS cannot be achieved with the stated assumptions.
General assumptions include no roundabouts or all-way STOP-controlled intersections along the facility; coordinated, semi-actuated traffic signals; arrival type 4; 120-s cycle time; protected left-turn phases; 0.45 weighted average *g/C* ratio; exclusive left-turn lanes with adequate queue storage provided at traffic signals; no exclusive right-turn lanes provided; no restrictive median; 2-mi facility length; 10% of traffic turns left and 10% turns right at each traffic signal; peak hour factor = 0.92; and base saturation flow rate = 1,900 pc/h/ln.
Additional assumptions for 30-mi/h facilities: signal spacing = 1,050 ft and 20 access points/mi.
Additional assumptions for 45-mi/h facilities: signal spacing = 1,500 ft and 10 access points/mi.

Exhibit 16-14 is provided for general planning use and should *not* be used to analyze any specific urban street facility or to make final decisions on important design features. A full operational analysis using this chapter's methodology is required for such specific applications.

The exhibit is useful, however, in evaluating the overall performance of a large number of urban streets within a jurisdiction, as a first pass to determine where problems might exist or arise, or to determine where improvements might be needed. Any urban street identified as likely to experience problems or need improvement, however, should then be subjected to a full operational analysis before any decisions on implementing specific improvements are made.

Daily service volumes are strongly affected by the *K*- and *D*-factors chosen as typical for the analysis. It is important that the values used for the facilities under study be reasonable. Also, if any characteristic is significantly different from the typical values used to develop Exhibit 16-14, particularly the weighted average *g*/*C* ratio and traffic signal spacing, the values taken from this exhibit will not be representative of the study facilities. In such cases, analysts are advised to develop their own generalized service volume tables by using representative local values or to proceed to a full operational analysis.

ACTIVE TRAFFIC MANAGEMENT STRATEGIES

Active traffic management (ATM) consists of the dynamic and continuous monitoring and control of traffic operations on a facility to improve facility performance. Examples of ATM measures on urban streets include congestion pricing zones, adaptive/responsive signal control, demand metering, changeable message signs, incident response, and work zone management. ATM measures can influence both the nature of the demand for the facility and the ability of the facility to deliver the capacity tailored to serve the demand. ATM measures can boost facility performance to the same extent as adding a conventional lane of capacity.

Other advanced design and management measures not included in the definition of ATM can also significantly boost facility performance. These non-ATM measures include lane treatments (bus lanes, bus streets, and reversible lanes), advanced interchange and intersection designs (divergent diamond interchanges, single-point urban interchanges, Michigan indirect left-turn intersections, and continuous flow intersections), and access management. These measures generally boost facility performance through the cost-effective addition of signal or lane capacity or both in unconventional ways to the facility.

More information on ATM measures and methods for their evaluation can be found in Chapter 35, Active Traffic Management.

4. EXAMPLE PROBLEMS

This part of the chapter describes the application of the automobile, pedestrian, bicycle, and transit methodologies through a series of example problems. Exhibit 16-15 provides an overview of these problems. The focus of the examples is to illustrate the multimodal facility evaluation process. An operational analysis level is used for all examples. The planning and preliminary engineering analysis level is identical to the operational analysis level in terms of the calculations except that default values are used when field-measured values are not available.

Exhibit 16-15
Example Problems

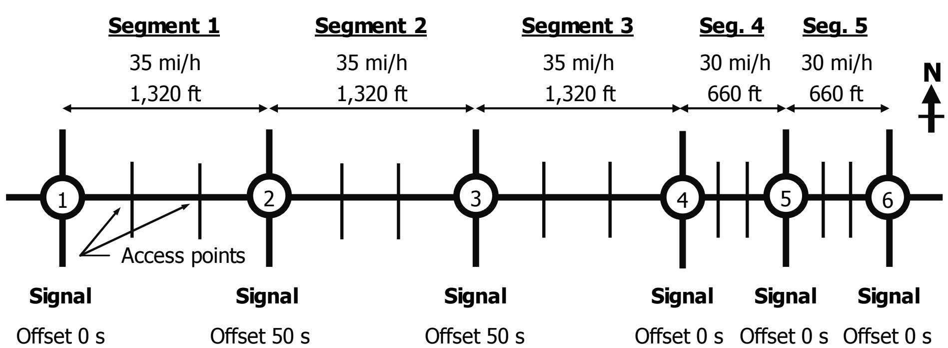
Problem Number	Description	Analysis Level
1	Auto-oriented urban street	Operational
2	Widen the sidewalks and add bicycle lanes on both sides of facility	Operational
3	Widen the sidewalks and add parking on both sides of facility	Operational

EXAMPLE PROBLEM 1: AUTO-ORIENTED URBAN STREET

The Urban Street Facility

A 1-mi urban street facility is shown in Exhibit 16-16. It is located in a downtown area and oriented in an east–west travel direction. The facility consists of five segments with a signalized boundary intersection for each segment. Segments 1, 2, and 3 are 1,320 ft long and have a speed limit of 35 mi/h. Segments 4 and 5 are 660 ft long and have a speed limit of 30 mi/h. Each segment has two access point intersections.

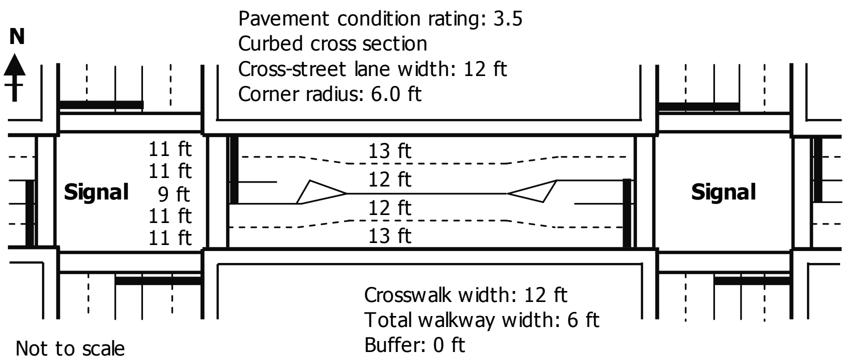
Exhibit 16-16
Example Problem 1: Urban Street Schematic



Segments 1, 2, and 3 pass through a mixture of office and strip commercial. Segments 4 and 5 are in a built-up shopping area.

The geometry of the typical street segment is shown in Exhibit 16-17. It is the same for each segment. The street has a curbed, four-lane cross section with two lanes in each direction. There is a 1.5-ft curb-and-gutter section on each side of the street. There are 200-ft left-turn bays on each approach to each signalized intersection. Right-turn vehicles share the outside lane with through vehicles on each intersection approach. A 6-ft sidewalk is provided on each side of the street adjacent to the curb. No fixed objects are located along the outside of the sidewalk. Midsegment pedestrian crossings are legal. No bicycle lanes are provided on the facility or its cross streets. No parking is allowed along the street.

Exhibit 16-17
Example Problem 1:
Segment Geometry



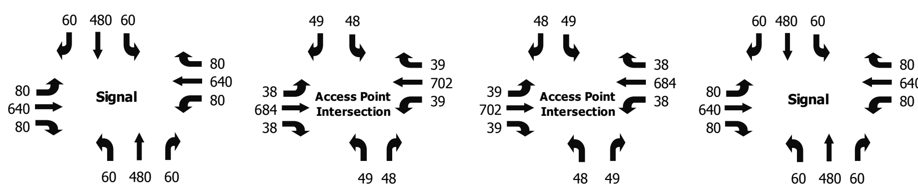
The Question

What are the travel speed and LOS of the automobile, pedestrian, bicycle, and transit modes in both directions of travel along the facility?

The Facts

The traffic counts for one segment are shown in Exhibit 16-18. The counts are the same for all of the other segments. The counts were taken during the 15-min analysis period of interest. However, they have been converted to hourly flow rates.

Exhibit 16-18
Example Problem 1:
Intersection Turn Movement Counts



The signalization conditions are shown in Exhibit 16-19. The conditions shown are identified as belonging to Signalized Intersection 1; however, they are the same for the other signalized intersections (with exception of offset). The signals operate with coordinated–actuated control. The left-turn movements on the northbound and southbound approaches operate under permitted control. The left-turn movements on the major street operate as protected–permitted in a lead–lead sequence.

Exhibit 16-19 indicates that the passage time for each phase is 2.0 s. The minimum green setting is 5 s for the major-street left-turn phases and 18 s for the cross-street phases. The offset to Phase 2 (the reference phase) end-of-green interval is 0.0 s. The offset for each of the other intersections is shown in Exhibit 16-16. A fixed-force mode is used to ensure coordination is maintained. The cycle length is 100 s.

Geometric conditions and traffic characteristics for Signalized Intersection 1 are shown in Exhibit 16-20. They are the same for the other signalized intersections. The movement numbers follow the numbering convention shown in Exhibit 18-2 of Chapter 18.

Exhibit 16-19
Example Problem 1: Signal Conditions for Intersection 1

Signalized Intersection 1

General Information 19

Cross Street:	First Avenue	Analysis Period:	AM peak

Phase Sequence and Left-Turn Mode

Major street sequence (movement numbers shown)	5 & 1 left leading	Cross street sequence (movement numbers shown)	No exclusive phase for 3 or 7
Major street left-turn mode (movement numbers shown)	5/1 Protected+Permitted	Cross street left-turn mode (movement numbers shown)	3/7 Permitted

Phase Settings

Approach	Eastbound		Westbound		Northbound		Southbound	
Phase number	5	2	1	6		8		4
Movement	L	T+R	L	T+R		L+T+R		L+T+R
Lead/lag left-turn phase	Lead	--	Lead	--		--		--
Left-turn mode	Pr/Pm	--	Pr/Pm	--		Perm.		Perm.
Passage time, s	2.0	--	2.0	--		2.0		2.0
Minimum green, s	5	--	5	--		18		18
Yellow + red clear, s	4.0	4.0	4.0	4.0		4.0		4.0
Phase split, s	20	45	20	45		35		35
Recall	No	--	No	--	No	No	No	No
Dual entry	No	Yes	No	Yes	No	Yes	No	Yes

Ref. Phase	2	Offset, s:	0	Offset Ref.: End of Green	Force Mode: Fixed
		Cycle, s:	100		

Enable Simultaneous Gap-Out?
Phase Group 1,2,5,6: ☑ Phase Group 3,4,7,8: ☑

Enable Dallas Left-Turn Phasing?
Phases 1,2,5,6: ☐ Phases 3,4,7,8: ☐

Exhibit 16-20
Example Problem 1: Geometric Conditions and Traffic Characteristics for Signalized Intersection 1

Signalized Intersection 1

Signalized Intersection Input Data *(In each column, enter the volume and lanes data. For all other blue cells, enter values only if there is one or more lanes.)*

Approach	Eastbound			Westbound			Northbound			Southbound		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Movement number	5	2	12	1	6	16	3	8	18	7	4	14
Volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
Lanes	1	2	0	1	2	0	1	2	0	1	2	0
Turn bay length, ft	200			200			200			200		
Sat. flow rate, veh/h/ln	1760	1829		1760	1829		1826	1838		1826	1838	
Platoon ratio	1.000	1.333		1.000	1.333		1.000	1.000		1.000	1.000	
Initial queue, veh	0	0		0	0		0	0		0	0	
Speed limit, mph	35	35	35	35	35	35	35	35	35	35	35	35
Stop line det. length, ft	40			40			40	40		40	40	
Max. allow. hdwy, s/ve	3.9			3.9			3.9	2.9		3.9	2.9	

The saturation flow rate is determined by using the procedure described in Chapter 18. All intersection movements include 3% heavy vehicles. The segment and intersection approaches are effectively level. No parking is allowed along the facility or its cross-street approaches. With a few exceptions (discussed below), local buses stop on the eastbound and westbound approaches to each signalized intersection at a rate of 3 buses/h.

Arrivals for all cross-street movements are effectively random, so a platoon ratio of 1.00 is used. The through movement arriving to the eastbound approach at Intersection 1 exhibits favorable progression from an upstream signal, so a platoon ratio of 1.33 is used. For similar reasons, a ratio of 1.33 is also used for the through movement arriving to the westbound approach at Intersection 6. Right-turn-on-red volume is estimated at 5.0% of the right-turn volume.

Each segment has a barrier curb along the outside of the street in each direction of travel. Allowing for the upstream signal width, the percentage of the segment length with curb is estimated at 94% for Segments 1, 2, and 3. It is estimated as 88% for Segments 4 and 5.

The traffic and lane assignment data for the two access point intersections for Segment 1 are shown in Exhibit 16-21. These data are the same for the other segments; however, the access point locations (shown in the first column) are reduced by one-half for Segments 4 and 5. The movement numbers follow the numbering convention shown in Exhibit 19-3 of Chapter 19, Two-Way STOP-Controlled Intersections. There are no turn bays on the segment at the two access point intersections.

Exhibit 16-21
Example Problem 1: Access Point Data

Access Point Input Data													
Access	Approach	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
Point	Movement	L	T	R	L	T	R	L	T	R	L	T	R
Location,ft	Movement number	1	2	3	4	5	6	7	8	9	10	11	12
440	Volume, veh/h	38	684	38	39	702	39	49	0	48	48	0	49
West end	Lanes	0	2	0	0	2	0	1	0	1	1	0	1
880	Volume, veh/h	39	702	39	38	684	38	48	0	49	49	0	48
	Lanes	0	2	0	0	2	0	1	0	1	1	0	1

A low wall is located along about 25% of the sidewalk in Segments 1, 2, and 3. In contrast, 10% of the sidewalk along Segments 4 and 5 is adjacent to a low wall, 35% to a building face, and 15% to a window display.

Office and strip commercial activity along Segments 1, 2, and 3 generates a pedestrian volume of 100 p/h on the adjacent sidewalks and crosswalks. Shopping activity along Segments 4 and 5 generates a pedestrian volume of 300 p/h on the adjacent sidewalks and crosswalks. A lack of bicycle lanes has discouraged bicycle traffic on the facility and its cross streets; however, a bicycle volume of 1.0 bicycle/h is entered for each intersection approach.

Local buses stop on the eastbound and westbound approaches to each signalized intersection, with the exception of Intersection 5. There are no stops on either approach to Intersection 5. However, transit stops are provided along the facility at 0.25-mi intervals, so the service is considered to be local. As a result, the westbound transit frequency on Segment 5 and the eastbound transit frequency on Segment 4 are considered to be the same as for the adjacent segments (i.e., 3 buses/h). The bus dwell time at each stop averages 20 s. Buses arrive within 5 min of their scheduled time about 75% of the time and have a load factor of 0.80 passengers/seat. Each bus stop has a bench but no shelter.

Outline of Solution

This section outlines the results of the facility evaluation. To complete this evaluation, the automobile, pedestrian, and bicycle methodologies in Chapter 18 were used to evaluate each of the signalized intersections on the facility. The procedure in Chapter 19 was used to estimate pedestrian delay when crossing at a midsegment location. The automobile, pedestrian, bicycle, and transit methodologies in Chapter 17 were then used to evaluate both directions of travel on each segment. Finally, the methodologies described in Section 2 were used to evaluate all four travel modes in both directions of travel on the facility. The findings from each evaluation are summarized in the following three subparts.

Intersection Evaluation

The results of the evaluation of Intersection 1 (i.e., First Avenue) are shown in Exhibit 16-22. The results for Intersections 2, 3, and eastbound Intersection 4 are similar. In contrast, Intersections 5 and 6 are associated with a shorter segment length, lower speed limit, and higher pedestrian volume, so their operation is different from that of the other intersections. The results for Intersection 5 (i.e., Fifth Avenue) are shown in Exhibit 16-23. Intersection 6 and westbound Intersection 4 have similar results.

Exhibit 16-22
Example Problem 1: Intersection 1 Evaluation

Intersection	Approach	Eastbound			Westbound			Northbound			Southbound		
		Intersection Evaluation Summary											
First Avenue	***Basic Description***												
	Applicable lane assignments	L	T	RT	L	T	RT	L	T	RT	L	T	RT
	Primary movement number	5	2	12	1	6	16	3	8	18	7	4	14
	Vehicle volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
	Conflicting crosswalk volume, p/h		100			100			100			100	
	Bicycle volume, bicycle/h		1			1			1			1	
	Approach lanes, ln	1	2	0	1	2	0	1	2	0	1	2	0
	Vehicle Level of Service												
Int. delay, s/veh	Volume-to-capacity ratio	0.17	0.34	0.34	0.15	0.34	0.34	0.36	0.62	0.62	0.36	0.62	0.62
20.4	Control delay, s/veh	7.78	5.75	5.77	7.04	13.38	13.73	43.18	34.24	34.28	43.18	34.24	34.28
Int. level of service	Stop rate, stops/veh	0.39	0.20	0.20	0.32	0.48	0.49	0.85	0.77	0.77	0.85	0.77	0.77
C	Level of service	**A**	**A**	**A**	**A**	**B**	**B**	**D**	**C**	**C**	**D**	**C**	**C**
	Pedestrian Level of Service												
	Corner location	Adjacent to Eastbound			Adjacent to Westbound			Adjacent to Northbound			Adjacent to Southbound		
	Corner circulation area, ft2/p	93.7			93.7			93.7			93.7		
	Crosswalk location			Crossing major			Crossing major			Crossing minor			Crossing minor
	Crosswalk circulation area, ft2/p			75.9			75.9			82.4			82.4
	Pedestrian delay, s/p			42.3			42.3			42.3			42.3
	Pedestrian LOS score			2.75			2.75			2.66			2.66
	Level of service			**C**			**C**			**B**			**B**
	Bicycle Level of Service												
	Bicycle delay, s/bicycle	n.a.			n.a.			n.a.			n.a.		
	Bicycle LOS score	3.72			3.72			2.87			2.87		
	Level of service	**D**			**D**			**C**			**C**		

Exhibit 16-23
Example Problem 1: Intersection 5 Evaluation

Intersection	Approach	Eastbound			Westbound			Northbound			Southbound		
		Intersection Evaluation Summary											
Fifth Avenue	***Basic Description***												
	Applicable lane assignments	L	T	RT	L	T	RT	L	T	RT	L	T	RT
	Primary movement number	5	2	12	1	6	16	3	8	18	7	4	14
	Vehicle volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
	Conflicting crosswalk volume, p/h		300			300			300			300	
	Bicycle volume, bicycle/h		1			1			1			1	
	Approach lanes, ln	1	2	0	1	2	0	1	2	0	1	2	0
	Vehicle Level of Service												
Int. delay, s/veh	Volume-to-capacity ratio	0.16	0.34	0.34	0.16	0.34	0.34	0.36	0.62	0.62	0.36	0.62	0.62
20.2	Control delay, s/veh	7.73	8.74	8.31	7.63	9.84	9.48	43.10	34.13	34.17	43.10	34.13	34.17
Int. level of service	Stop rate, stops/veh	0.38	0.31	0.29	0.37	0.35	0.34	0.86	0.78	0.78	0.86	0.78	0.78
C	Level of service	**A**	**A**	**A**	**A**	**A**	**A**	**D**	**C**	**C**	**D**	**C**	**C**
	Pedestrian Level of Service												
	Corner location	Adjacent to Eastbound			Adjacent to Westbound			Adjacent to Northbound			Adjacent to Southbound		
	Corner circulation area, ft2/p	14.8			14.8			14.8			14.8		
	Crosswalk location			Crossing major			Crossing major			Crossing minor			Crossing minor
	Crosswalk circulation area, ft2/p			24.5			24.5			26.7			26.7
	Pedestrian delay, s/p			42.3			42.3			42.3			42.3
	Pedestrian LOS score			2.70			2.70			2.62			2.62
	Level of service			**B**			**B**			**B**			**B**
	Bicycle Level of Service												
	Bicycle delay, s/bicycle	n.a.			n.a.			n.a.			n.a.		
	Bicycle LOS score	3.72			3.72			2.87			2.87		
	Level of service	**D**			**D**			**C**			**C**		

Both exhibits indicate that the major-street vehicular through movements (i.e., eastbound Movement 2 and westbound Movement 6) operate with very low delay and few stops. The LOS is A and B for the eastbound and westbound through movements, respectively.

Pedestrian circulation area on the corners of Intersection 1 is generous, with pedestrians having the ability to move in their desired path without conflict. Corner circulation area at Intersection 5 is restricted, with pedestrians having very limited ability to pass slower pedestrians.

At Intersection 1, the low pedestrian volume results in generous crosswalk circulation area. Pedestrians rarely need to adjust their path to avoid conflicts. In contrast, the high pedestrian volume at Intersection 5 results in a constrained crosswalk circulation area. Pedestrians frequently adjust their path to avoid conflict. At each intersection, pedestrians experience an average wait of about 42 s at the corner to cross the street in any direction. This delay is lengthy, and some pedestrians may not comply with the signal indications. At Intersection 1, the pedestrian LOS is C for the major-street crossing and B for the minor-street crossing. At Intersection 5, the pedestrian LOS is B for the major-street and minor-street crossings.

Bicycle lanes are not provided at any intersection, so bicycle delay is not computed. The lack of a bicycle lane combined with a moderately high traffic volume results in a bicycle LOS D on the eastbound and westbound approaches of Intersection 1 and Intersection 5.

Segment Evaluation

The results of the evaluation of Segment 1 (i.e., First Avenue to Second Avenue) are shown in Exhibit 16-24. The results for Segments 2 and 3 are similar. In contrast, Segments 4 and 5 are associated with a shorter segment length, lower speed limit, and higher pedestrian volume, so their operation is different from that of the other intersections. The results for Segment 5 (i.e., Fifth Avenue to Sixth Avenue) are shown in Exhibit 16-25. Segment 4 has similar results.

Exhibit 16-24
Example Problem 1: Segment 1 Evaluation

Segment	Segment Evaluation Summary		
	Travel Direction	Eastbound	Westbound
First Avenue to Second Avenue Segment length, ft 1,320	***Basic Description***		
	Speed limit, mi/h	35	35
	Vehicle volume, veh/h	800	800
	Through lanes, ln	2	2
	Vehicle Level of Service		
	Base free-flow speed, mi/h	40.3	40.3
	Travel speed, mi/h	23.8	23.2
	Spatial stop rate, stops/mi	1.77	1.92
	Level of service	**C**	**C**
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	593.9	593.9
	Pedestrian travel speed, ft/s	3.54	3.54
	Pedestrian LOS score	3.76	3.76
	Level of service	**D**	**D**
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	No bicycle lane.	No bicycle lane.
	Bicycle LOS score	4.24	4.24
	Level of service	**D**	**D**
	Transit Level of Service		
	Transit travel speed, mi/h	12.7	12.5
	Transit LOS score	3.16	3.19
	Level of service	**C**	**C**

Exhibit 16-25
Example Problem 1: Segment 5 Evaluation

Segment	Segment Evaluation Summary		
	Travel Direction	Eastbound	Westbound
Fifth Avenue to Sixth Avenue Segment length, ft 660	***Basic Description***		
	Speed limit, mi/h	30	30
	Vehicle volume, veh/h	800	800
	Through lanes, ln	2	2
	Vehicle Level of Service		
	Base free-flow speed, mi/h	37.9	37.9
	Travel speed, mi/h	17.6	17.3
	Spatial stop rate, stops/mi	2.68	2.80
	Level of service	**D**	**D**
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	153.3	153.3
	Pedestrian travel speed, ft/s	3.18	3.18
	Pedestrian LOS score	3.67	3.67
	Level of service	**D**	**D**
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	No bicycle lane.	No bicycle lane.
	Bicycle LOS score	4.48	4.48
	Level of service	**E**	**E**
	Transit Level of Service		
	Transit travel speed, mi/h	7.7	17.3
	Transit LOS score	3.64	2.79
	Level of service	**D**	**C**

Exhibit 16-24 indicates that the vehicular through movements on Segment 1 in the eastbound and westbound travel directions have a travel speed of 24 and 23 mi/h, respectively (i.e., about 58% of the base free-flow speed). The LOS of each movement is C. In contrast, Exhibit 16-25 indicates that the through movements have a travel speed of only about 17 mi/h on Segment 5 (or 46% of the base free-flow speed), which is LOS D. Vehicles stop at a rate of about 1.8 stops/mi on Segment 1 and about 2.7 stops/mi on Segment 5.

Pedestrian space on the sidewalk along the segment is generous on Segment 1 and adequate on Segment 5. These characterizations are based on

Exhibit 16-11 and an assumed dominance of platoon flow for Segments 4 and 5. Pedestrians on these sidewalks can walk freely without having to alter their path to accommodate other pedestrians. The segment travel speed (3.54 ft/s for Segment 1 and 3.18 ft/s for Segment 5) is adequate, but would desirably exceed 4.0 ft/s. Nevertheless, the sidewalk is near the traffic lanes and crossing the street at a midsegment location can be difficult. As a result, the pedestrian LOS is D on all segments.

Bicycle lanes are not provided along the segment, so bicycle travel speed is not computed. The lack of a bicycle lane combined with a moderately high traffic volume results in a bicycle LOS D for both directions of travel on Segment 1. Bicycle service on Segment 5 is also poor. However, the short spacing between access points on Segment 5, relative to Segment 1, further degrades service quality such that the bicycle LOS on Segment 5 is E.

Transit travel speed is about 12 mi/h on Segment 1 and corresponds to LOS C. On Segment 5, the travel speed is about 8 mi/h and 17 mi/h in the eastbound and westbound directions, respectively. The low speed for the eastbound direction results in LOS D. The higher speed for the westbound direction is due to the lack of a westbound transit stop on Segment 5. It results in LOS C for this direction.

Facility Evaluation

The methodology described in Section 2 is used to compute the aggregate performance measures for each travel direction along the facility. The results are shown in Exhibit 16-26. This exhibit indicates that the vehicle travel speed is about 22 mi/h in each travel direction (or 56% of the base free-flow speed). An overall LOS C applies to both vehicular movements on the facility; however, it is noted that LOS D applies to Segments 4 and 5. Vehicles incur stops along the facility at a rate of about 1.9 stops/mi.

Exhibit 16-26
Example Problem 1: Facility Evaluation

	Facility Evaluation Summary		
	Travel Direction	**Eastbound**	**Westbound**
Facility length, ft 5,280	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	39.7	39.7
	Travel speed, mi/h	22.3	22.1
	Spatial stop rate, stops/mi	1.86	1.93
	Level of service	**C**	**C**
	Poorest perf. segment LOS	D	D
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	298.6	298.6
	Pedestrian travel speed, ft/s	3.4	3.4
	Pedestrian LOS score	3.73	3.74
	Level of service	**D**	**D**
	Poorest perf. segment LOS	D	D
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	No bicycle lane.	No bicycle lane.
	Bicycle LOS score	4.30	4.30
	Level of service	**E**	**E**
	Poorest perf. segment LOS	E	E
	Transit Level of Service		
	Transit travel speed, mi/h	12.4	12.3
	Transit LOS score	3.15	3.16
	Level of service	**C**	**C**
	Poorest perf. segment LOS	D	D

Pedestrian space on the sidewalk along the facility is generous. Pedestrians on the sidewalks can walk freely without having to alter their path to accommodate other pedestrians. The facility travel speed of about 3.4 ft/s is adequate, but would desirably exceed 4.0 ft/s. Nevertheless, the sidewalk is near the traffic lanes and crossing the street at a midsegment location can be difficult. As a result, the pedestrian LOS is D for both directions of travel.

Bicycle lanes are not provided along the facility, so bicycle travel speed is not computed. The lack of a bicycle lane combined with a moderately high traffic volume results in an overall bicycle LOS E for both directions of travel.

Transit travel speed is about 12 mi/h on the facility in each direction of travel. An overall LOS C is assigned to each direction. The lower speed on westbound Segment 4 and eastbound Segment 5 is noted to result in LOS D for those segments.

EXAMPLE PROBLEM 2: PEDESTRIAN AND BICYCLE IMPROVEMENTS

The Urban Street Facility

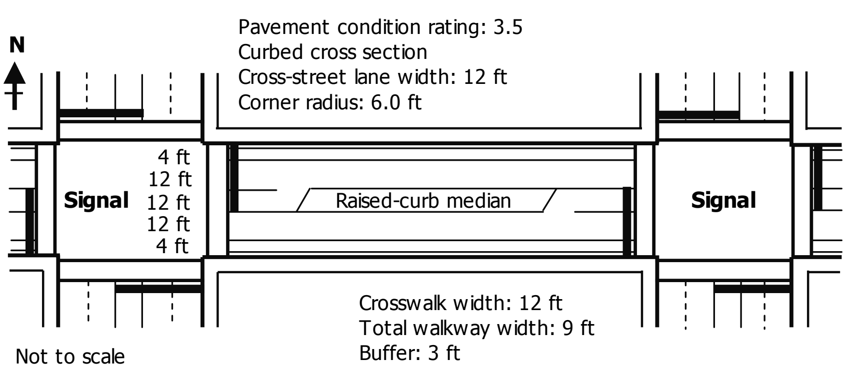
The 1-mi urban street facility shown in Exhibit 16-16 is being considered for geometric design modifications to improve pedestrian and bicycle service. The following changes to the facility are proposed:

- Eliminate one vehicle lane in each direction,
- Add a 12-ft raised-curb median,
- Add a 4-ft bicycle lane in each direction,
- Increase the total walkway width to 9 ft,
- Add a 3-ft buffer between the sidewalk and the curb, and
- Add bushes to the buffer using a 10-ft spacing.

No fixed objects are located along the outside of the sidewalk. The analysis for Example Problem 1 represents the existing condition, against which this alternative will be evaluated.

The geometry of the typical street segment is shown in Exhibit 16-27. It is the same for each segment. Additional segment details are provided in the discussion for Example Problem 1.

Exhibit 16-27
Example Problem 2: Segment Geometry



The Question

What are the travel speed and LOS of the automobile, pedestrian, bicycle, and transit modes in both directions of travel along the facility?

The Facts

The traffic counts, signalization, and intersection geometry are listed in Exhibit 16-18 to Exhibit 16-21. They are unchanged from Example Problem 1.

Outline of Solution

This section outlines the results of the facility evaluation. To complete this evaluation, the automobile, pedestrian, and bicycle methodologies in Chapter 18 were used to evaluate each of the signalized intersections on the facility. The procedure in Chapter 19 was used to estimate pedestrian delay when crossing at a midsegment location. The automobile, pedestrian, bicycle, and transit methodologies in Chapter 17 were then used to evaluate both directions of travel on each segment. Finally, the methodologies described in Section 2 were used to evaluate all four travel modes in both directions of travel on the facility. The findings from each evaluation are summarized in the following three subparts.

Intersection Evaluation

The results of the evaluation of Intersection 1 (i.e., First Avenue) are shown in Exhibit 16-28. The results for Intersections 2, 3, and eastbound Intersection 4 are similar. In contrast, Intersections 5 and 6 are associated with a shorter segment length, lower speed limit, and higher pedestrian volume, so their operation is different from that of the other intersections. The results for Intersection 5 (i.e., Fifth Avenue) are shown in Exhibit 16-29. Intersection 6 and westbound Intersection 4 have similar results.

Exhibit 16-28
Example Problem 2: Intersection 1 Evaluation

	Intersection Evaluation Summary												
Intersection	Approach	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
First Avenue	***Basic Description***												
	Applicable lane assignments	L	T	RT	L	T	RT	L	T	RT	L	T	RT
	Primary movement number	5	2	12	1	6	16	3	8	18	7	4	14
	Vehicle volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
	Conflicting crosswalk volume, p/h		100			100			100			100	
	Bicycle volume, bicycle/h		1			1			1			1	
	Approach lanes, ln	1	1	0	1	1	0	1	2	0	1	2	0
	Vehicle Level of Service												
Int. delay, s/veh	Volume-to-capacity ratio	0.20	0.68	0.68	0.18	0.68	0.68	0.36	0.62	0.62	0.36	0.62	0.62
21.8	Control delay, s/veh	10.70	9.77	9.77	8.61	14.36	14.36	43.19	34.26	34.30	43.19	34.26	34.30
Int. level of service	Stop rate, stops/veh	0.54	0.24	0.24	0.45	0.46	0.46	0.85	0.77	0.77	0.85	0.77	0.77
C	Level of service	**B**	**A**	**A**	**A**	**B**	**B**	**D**	**C**	**C**	**D**	**C**	**C**
	Pedestrian Level of Service												
	Corner location		Adjacent to Eastbound			Adjacent to Westbound			Adjacent to Northbound			Adjacent to Southbound	
	Corner circulation area, ft2/p		282.1			282.1			282.1			282.1	
	Crosswalk location			Crossing major			Crossing major			Crossing minor			Crossing minor
	Crosswalk circulation area, ft2/p			69.7			69.7			82.5			82.4
	Pedestrian delay, s/p			42.3			42.3			42.3			42.3
	Pedestrian LOS score			2.63			2.63			2.66			2.66
	Level of service			**B**			**B**			**B**			**B**
	Bicycle Level of Service												
	Bicycle delay, s/bicycle		8.3			8.3			n.a.			n.a.	
	Bicycle LOS score		2.99			2.99			2.77			2.77	
	Level of service		**C**			**C**			**C**			**C**	

Both exhibits indicate that the vehicular through movements on the facility (i.e., eastbound Movement 2 and westbound Movement 6) operate with low delay and few stops. For the eastbound through movement, the LOS is A at Intersection 1 and B at Intersection 5. The LOS is B for the westbound through movement at both intersections. Relative to Example Problem 1, the delay for the through movements has increased by a few seconds at Intersection 1 and by about 8 s at Intersection 5. This increase is sufficient to lower the LOS designation for the eastbound through movement at Intersection 5 (i.e., from A to B).

Exhibit 16-29
Example Problem 2:
Intersection 5 Evaluation

Intersection	Intersection Evaluation Summary												
Intersection	Approach		**Eastbound**			**Westbound**			**Northbound**			**Southbound**	
Fifth Avenue	***Basic Description***												
	Applicable lane assignments	L	T	RT	L	T	RT	L	T	RT	L	T	RT
	Primary movement number	5	2	12	1	6	16	3	8	18	7	4	14
	Vehicle volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
	Conflicting crosswalk volume, p/h		300			300			300			300	
	Bicycle volume, bicycle/h		1			1			1			1	
	Approach lanes, ln	1	1	0	1	1	0	1	2	0	1	2	0
	Vehicle Level of Service												
Int. delay, s/veh	Volume-to-capacity ratio	0.21	0.68	0.68	0.21	0.68	0.68	0.36	0.62	0.62	0.36	0.62	0.62
24.5	Control delay, s/veh	11.53	17.32	17.32	11.72	16.79	16.79	43.12	34.18	34.23	43.12	34.18	34.23
Int. level of service	Stop rate, stops/veh	0.59	0.58	0.58	0.59	0.56	0.56	0.86	0.78	0.78	0.86	0.78	0.78
C	Level of service	**B**	**B**	**B**	**B**	**B**	**B**	**D**	**C**	**C**	**D**	**C**	**C**
	Pedestrian Level of Service												
	Corner location		Adjacent to Eastbound			Adjacent to Westbound			Adjacent to Northbound			Adjacent to Southbound	
	Corner circulation area, ft2/p		77.6			77.6			77.6			77.6	
	Crosswalk location			Crossing major			Crossing major			Crossing minor			Crossing minor
	Crosswalk circulation area, ft2/p			22.4			22.4			26.6			26.6
	Pedestrian delay, s/p			42.3			42.3			42.3			42.3
	Pedestrian LOS score			2.55			2.55			2.62			2.62
	Level of service			**B**			**B**			**B**			**B**
	Bicycle Level of Service												
	Bicycle delay, s/bicycle		8.3			8.3			n.a.			n.a.	
	Bicycle LOS score		2.99			2.99			2.77			2.77	
	Level of service		**C**			**C**			**C**			**C**	

Pedestrian circulation area on the corners of Intersections 1 and 5 is generous, with few instances of conflict. This condition is greatly improved from Example Problem 1 and reflects the provision of wider sidewalks.

Relative to Example Problem 1, the reduction in through lanes has reduced the time provided to pedestrians to cross the major street. This reduction resulted in larger pedestrian groups using the crosswalk and a small reduction in crosswalk pedestrian space. At Intersection 1, pedestrian space is still generous, with few instances of conflict. At Intersection 5, the problem is amplified by a higher pedestrian demand. Pedestrian space in the crosswalks is constrained, and pedestrians are likely to find that their ability to pass slower pedestrians is limited.

At each intersection, pedestrians experience an average wait of about 42 s at the corner to cross the street in any direction. This condition has not changed from Example Problem 1.

At both intersections, the pedestrian LOS is B for the major-street and minor-street crossings. Relative to Example Problem 1, the pedestrian LOS score has improved by about the same amount at all intersections. At Intersection 1, this change is sufficient to result in a change in service level (i.e., from C to B).

Bicyclists using the bicycle lanes are expected to be delayed about 8 s/bicycle on both the eastbound and westbound approaches to each intersection. This level of delay is desirably low. However, the bicycle lane is relatively narrow at 4 ft, which leads to LOS C on the eastbound and westbound approaches of both intersections. This LOS is noted to be an improvement over the LOS D identified in Example Problem 1.

Segment Evaluation

The results of the evaluation of Segment 1 (i.e., First Avenue to Second Avenue) are shown in Exhibit 16-30. The results for Segments 2 and 3 are similar. In contrast, Segments 4 and 5 are associated with a shorter segment length, lower speed limit, and higher pedestrian volume, so their operation is different from the other intersections. The results for Segment 5 (i.e., Fifth Avenue to Sixth Avenue) are shown in Exhibit 16-31. Segment 4 has similar results.

Exhibit 16-30
Example Problem 2: Segment 1 Evaluation

Segment	Segment Evaluation Summary		
	Travel Direction	Eastbound	Westbound
First Avenue to Second Avenue	***Basic Description***		
	Speed limit, mi/h	35	35
	Vehicle volume, veh/h	800	800
	Through lanes, ln	1	1
Segment length, ft 1,320	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	37.4	37.4
	Travel speed, mi/h	21.3	21.3
	Spatial stop rate, stops/mi	1.83	1.82
	Level of service	**C**	**C**
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	809.9	809.9
	Pedestrian travel speed, ft/s	3.55	3.55
	Pedestrian LOS score	2.74	2.74
	Level of service	**B**	**B**
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	13.18	13.18
	Bicycle LOS score	3.87	3.87
	Level of service	**D**	**D**
	Transit Level of Service		
	Transit travel speed, mi/h	10.3	10.4
	Transit LOS score	3.42	3.42
	Level of service	**C**	**C**

Exhibit 16-31
Example Problem 2: Segment 5 Evaluation

Segment	Segment Evaluation Summary		
	Travel Direction	Eastbound	Westbound
Fifth Avenue to Sixth Avenue	***Basic Description***		
	Speed limit, mi/h	30	30
	Vehicle volume, veh/h	800	800
	Through lanes, ln	1	1
Segment length, ft 660	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	35.3	35.3
	Travel speed, mi/h	12.7	13.2
	Spatial stop rate, stops/mi	4.74	4.47
	Level of service	**E**	**E**
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	225.4	225.4
	Pedestrian travel speed, ft/s	3.18	3.18
	Pedestrian LOS score	2.72	2.72
	Level of service	**B**	**B**
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	11.75	11.75
	Bicycle LOS score	4.10	4.10
	Level of service	**D**	**D**
	Transit Level of Service		
	Transit travel speed, mi/h	5.2	13.2
	Transit LOS score	4.00	3.14
	Level of service	**D**	**C**

Exhibit 16-30 indicates that the vehicular through movements on Segment 1 in the eastbound and westbound travel directions have a travel speed of about 21 mi/h (i.e., about 57% of the base free-flow speed). LOS C applies to both movements. In contrast, Exhibit 16-31 indicates that the through movements have a travel speed of only about 13 mi/h on Segment 5 (or 37% of the base free-flow speed), which is LOS E. Vehicles stop at a rate of about 1.8 stops/mi on Segment 1 and about 4.6 stops/mi on Segment 5. Relative to Example Problem 1, conditions have notably degraded for vehicles traveling along Segment 5.

Pedestrian space on the sidewalk along the segment is generous on Segment 1. Pedestrians can walk freely without having to alter their path to accommodate other pedestrians. Pedestrian space is adequate on Segment 5, with pedestrians in platoons occasionally needing to adjust their path to avoid conflict. These characterizations are based on Exhibit 16-11 and an assumed dominance of platoon flow for Segments 4 and 5. Relative to Example Problem 1, the sidewalks are more distant from the traffic lanes and crossing the street at a midsegment location is easier because of the raised curb median. As a result, the pedestrian LOS is B on all segments.

Bicyclists using the bicycle lanes experience a travel speed of 13 mi/h on Segment 1 and 12 mi/h on Segment 5. This travel speed is considered desirable. However, the bicycle lane is relatively narrow at 4 ft, so a bicycle LOS D results for both directions of travel on each segment. While still poor, the bicycle LOS scores indicate that bicycle service has improved on both segments relative to that found in Example Problem 1. In fact, the bicycle LOS on Segment 5 has improved by one letter designation.

Transit travel speed is 10 mi/h on Segment 1 and corresponds to LOS C. On Segment 5, the travel speed is about 5 mi/h and 13 mi/h in the eastbound and westbound directions, respectively. The low speed for the eastbound direction results in LOS D. The higher speed for the westbound direction is due to the lack of a westbound transit stop on Segment 5. It results in LOS C. Relative to Example Problem 1, the slower vehicular travel speed has increased the transit LOS scores, but not enough to change the designated service level.

Facility Evaluation

The methodology described in Section 2 is used to compute the aggregate performance measures for each travel direction along the facility. The results are shown in Exhibit 16-32. This exhibit indicates that the vehicle travel speed is about 18 mi/h in each travel direction (or 49% of the base free-flow speed). An overall LOS D applies to vehicle travel in each direction on the facility. It is noted that LOS E applies to Segments 4 and 5. Vehicles incur stops along the facility at a rate of about 2.6 stops/mi. Relative to Example Problem 1, vehicular travel speed has dropped about 4 mi/h, and LOS has degraded one level for this scenario.

Exhibit 16-32
Example Problem 2: Facility Evaluation

	Facility Evaluation Summary		
	Travel Direction	**Eastbound**	**Westbound**
Facility length, ft 5,280	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	36.8	36.8
	Travel speed, mi/h	18.0	18.1
	Spatial stop rate, stops/mi	2.64	2.62
	Level of service	**D**	**D**
	Poorest perf. segment LOS	E	E
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	422.2	422.2
	Pedestrian travel speed, ft/s	3.4	3.4
	Pedestrian LOS score	2.74	2.74
	Level of service	**B**	**B**
	Poorest perf. segment LOS	B	B
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	12.8	12.8
	Bicycle LOS score	3.93	3.93
	Level of service	**D**	**D**
	Poorest perf. segment LOS	D	D
	Transit Level of Service		
	Transit travel speed, mi/h	9.3	9.3
	Transit LOS score	3.48	3.48
	Level of service	**C**	**C**
	Poorest perf. segment LOS	D	D

Pedestrian space on the sidewalk along the facility is generous. Pedestrians on the sidewalks can walk freely without having to alter their path to accommodate other pedestrians. Increasing the separation between the sidewalk and traffic lanes and improving pedestrians' ability to cross the street at midsegment locations (by adding a raised-curb median) have resulted in an overall pedestrian LOS B for both directions of travel. This level compares favorably with the LOS D indicated in Example Problem 1.

Bicyclists in the bicycle lanes are estimated to experience an average travel speed of about 13 mi/h. This travel speed is considered desirable. However, the 4-ft bicycle lane is relatively narrow and produces LOS D. This level is one level improved over that found for Example Problem 1.

Transit travel speed is about 9 mi/h on the facility in each direction of travel. An overall LOS C is assigned to each direction. Relative to Example Problem 1, the LOS designation is unchanged; however, the transit speed is slower, and the transit LOS score indicates a small reduction in service.

EXAMPLE PROBLEM 3: PEDESTRIAN AND PARKING IMPROVEMENTS

The Urban Street Facility

The 1-mi urban street facility shown in Exhibit 16-16 is being considered for geometric design modifications to improve parking and pedestrian service. The following changes to the facility are proposed:

- Eliminate one vehicle lane in each direction,
- Add a 12-ft raised-curb median,
- Add a 9.5-ft parking lane in each direction, and
- Increase the total walkway width to 7 ft.

No fixed objects will be located along the outside of the sidewalk. The on-street parking is expected to be occupied 50% of the time. Parking maneuvers are estimated to cause 1.8 s/veh additional delay on Segments 1, 2, and 3. On Segments 4 and 5, these maneuvers are estimated to cause 0.3 s/veh additional delay. The analysis for Example Problem 1 represents the existing condition, against which this alternative will be evaluated.

The geometry of the typical street segment is shown in Exhibit 16-33. It is the same for each segment. Additional segment details are provided in the discussion for Example Problem 1.

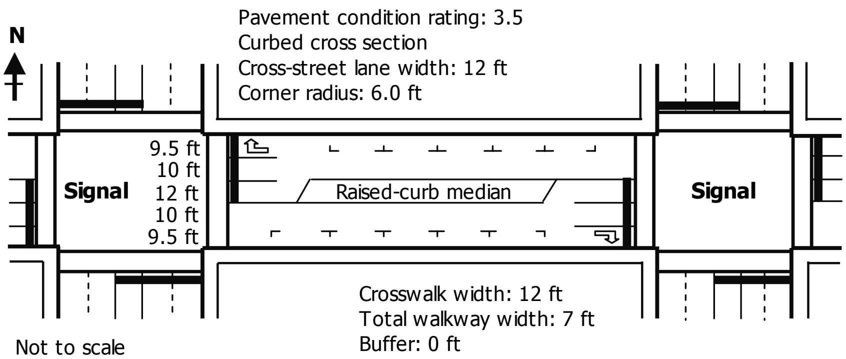
The Question

What are the travel speed and LOS of the automobile, pedestrian, bicycle, and transit modes in both directions of travel along the facility?

The Facts

The traffic counts, signalization, and intersection geometry are listed in Exhibit 16-18 to Exhibit 16-21. They are unchanged from Example Problem 1.

Exhibit 16-33
Example Problem 3:
Segment Geometry



Outline of Solution

This section outlines the results of the facility evaluation. To complete this evaluation, the automobile, pedestrian, and bicycle methodologies in Chapter 18 were used to evaluate each of the signalized intersections on the facility. The procedure in Chapter 19 was used to estimate pedestrian delay when crossing at a midsegment location. The automobile, pedestrian, bicycle, and transit methodologies in Chapter 17 were then used to evaluate both directions of travel on each segment. Finally, the methodologies described in Section 2 were used to evaluate all four travel modes in both directions of travel on the facility. The findings from each evaluation are summarized in the following three subparts.

Intersection Evaluation

The results of the evaluation of Intersection 1 (i.e., First Avenue) are shown in Exhibit 16-34. The results for Intersections 2, 3, and eastbound Intersection 4 are similar. In contrast, Intersections 5 and 6 are associated with a shorter segment length, lower speed limit, and higher pedestrian volume, so their operation is different from that of the other intersections. The results for Intersection 5 (i.e., Fifth Avenue) are shown in Exhibit 16-35. Intersection 6 and westbound Intersection 4 have similar results.

Exhibit 16-34
Example Problem 3:
Intersection 1 Evaluation

	Intersection Evaluation Summary												
Intersection	Approach	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
First Avenue	***Basic Description***												
	Applicable lane assignments	L	T	R	L	T	R	L	T	RT	L	T	RT
	Primary movement number	5	2	12	1	6	16	3	8	18	7	4	14
	Vehicle volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
	Conflicting crosswalk volume, p/h		100			100			100			100	
	Bicycle volume, bicycle/h		1			1			1			1	
	Approach lanes, ln	1	1	1	1	1	1	1	2	0	1	2	0
	Vehicle Level of Service												
Int. delay, s/veh	Volume-to-capacity ratio	0.19	0.59	0.09	0.16	0.59	0.09	0.36	0.62	0.62	0.36	0.62	0.62
21.8	Control delay, s/veh	10.01	7.99	9.00	7.40	16.60	11.49	43.19	34.26	34.30	43.19	34.26	34.30
Int. level of service	Stop rate, stops/veh	0.51	0.22	0.34	0.38	0.56	0.42	0.85	0.77	0.77	0.85	0.77	0.77
C	Level of service	**B**	**A**	**A**	**A**	**B**	**B**	**D**	**C**	**C**	**D**	**C**	**C**
	Pedestrian Level of Service												
	Corner location		Adjacent to Eastbound			Adjacent to Westbound			Adjacent to Northbound			Adjacent to Southbound	
	Corner circulation area, ft2/p		148.1			148.1			148.1			148.1	
	Crosswalk location			Crossing major			Crossing major			Crossing minor			Crossing minor
	Crosswalk circulation area, ft2/p			74.0			74.0			82.6			82.4
	Pedestrian delay, s/p			42.3			42.3			42.3			42.3
	Pedestrian LOS score			2.67			2.67			2.66			2.66
	Level of service			**B**			**B**			**B**			**B**
	Bicycle Level of Service												
	Bicycle delay, s/bicycle		n.a.			n.a.			n.a.			n.a.	
	Bicycle LOS score		4.27			4.27			2.83			2.83	
	Level of service		**E**			**E**			**C**			**C**	

Both exhibits indicate that the vehicular through movements on the facility (i.e., eastbound Movement 2 and westbound Movement 6) operate with very low delay and few stops. For the eastbound through movement, the LOS is A at Intersection 1 and B at Intersection 5. The LOS is B for the westbound through movement at both intersections. Relative to Example Problem 1, the delay for the through movements has increased by a few seconds at both intersections. However, this increase is sufficient to lower the LOS designation for only the eastbound through movement at Intersection 5.

Exhibit 16-35
Example Problem 3: Intersection 5 Evaluation

Intersection	Intersection Evaluation Summary												
Intersection	Approach	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
Fifth Avenue	***Basic Description***												
	Applicable lane assignments	L	T	R	L	T	R	L	T	RT	L	T	RT
	Primary movement number	5	2	12	1	6	16	3	8	18	7	4	14
	Vehicle volume, veh/h	80	640	80	80	640	80	60	480	60	60	480	60
	Conflicting crosswalk volume, p/h		300			300			300			300	
	Bicycle volume, bicycle/h		1			1			1			1	
	Approach lanes, ln	1	1	1	1	1	1	1	2	0	1	2	0
	Vehicle Level of Service												
Int. delay, s/veh	Volume-to-capacity ratio	0.18	0.59	0.10	0.17	0.59	0.10	0.36	0.62	0.62	0.36	0.62	0.62
21.6	Control delay, s/veh	9.60	11.83	4.74	9.25	13.32	6.16	43.12	34.18	34.22	43.12	34.18	34.22
Int. level of service	Stop rate, stops/veh	0.51	0.39	0.19	0.49	0.45	0.24	0.86	0.78	0.78	0.86	0.78	0.78
C	Level of service	**A**	**B**	**A**	**A**	**B**	**A**	**D**	**C**	**C**	**D**	**C**	**C**
	Pedestrian Level of Service												
	Corner location		Adjacent to Eastbound			Adjacent to Westbound			Adjacent to Northbound			Adjacent to Southbound	
	Corner circulation area, ft2/p		33.0			33.0			33.0			33.0	
	Crosswalk location			Crossing major			Crossing major			Crossing minor			Crossing minor
	Crosswalk circulation area, ft2/p			23.8			23.8			26.6			26.6
	Pedestrian delay, s/p			42.3			42.3			42.3			42.3
	Pedestrian LOS score			2.61			2.61			2.62			2.62
	Level of service			**B**			**B**			**B**			**B**
	Bicycle Level of Service												
	Bicycle delay, s/bicycle		n.a.			n.a.			n.a.			n.a.	
	Bicycle LOS score		4.27			4.27			2.83			2.83	
	Level of service		**E**			**E**			**C**			**C**	

Pedestrian circulation area on the corners of Intersection 1 is generous. However, corner circulation area at Intersection 5 is constrained, with pedestrians frequently needing to adjust their path to avoid slower pedestrians. Regardless, this condition is improved from Example Problem 1 and reflects the provision of wider sidewalks.

Relative to Example Problem 1, the reduction in lanes has reduced the time provided to pedestrians to cross the major street. This reduction resulted in larger pedestrian groups using the crosswalk and a slight reduction in crosswalk pedestrian space. At Intersection 1, pedestrian space is generous. However, pedestrian space is constrained at Intersection 5, with pedestrians having limited ability to pass slower pedestrians as they cross the street.

At each intersection, pedestrians experience an average wait of about 42 s at the corner to cross the street in any direction. At both intersections, the pedestrian LOS is B for the major-street crossing and the minor-street crossing. The LOS designation has improved at Intersection 1 by one letter, relative to Example Problem 1, and remains unchanged at Intersection 5.

Bicycle lanes are not provided at any intersection, so bicycle delay is not computed. The lack of a bicycle lane combined with a high traffic volume results in a bicycle LOS E on the eastbound and westbound approaches of Intersection 1 and Intersection 5. This level is noted to be worse than the LOS D identified in Example Problem 1 because the traffic volume per lane has doubled.

Segment Evaluation

The results of the evaluation of Segment 1 (i.e., First Avenue to Second Avenue) are shown in Exhibit 16-36. The results for Segments 2 and 3 are similar. In contrast, Segments 4 and 5 are associated with a shorter segment length, lower speed limit, and higher pedestrian volume, so their operation is different from that of the other intersections. The results for Segment 5 (i.e., Fifth Avenue to Sixth Avenue) are shown in Exhibit 16-37. Segment 4 has similar results.

Exhibit 16-36
Example Problem 3:
Segment 1 Evaluation

Segment	Segment Evaluation Summary		
	Travel Direction	**Eastbound**	**Westbound**
First Avenue to Second Avenue	***Basic Description***		
	Speed limit, mi/h	35	35
	Vehicle volume, veh/h	800	800
	Through lanes, ln	1	1
Segment length, ft 1,320	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	37.4	37.4
	Travel speed, mi/h	20.0	19.5
	Spatial stop rate, stops/mi	2.05	2.22
	Level of service	**C**	**C**
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	737.9	737.9
	Pedestrian travel speed, ft/s	3.55	3.55
	Pedestrian LOS score	2.89	2.89
	Level of service	**C**	**C**
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	No bicycle lane.	No bicycle lane.
	Bicycle LOS score	4.70	4.70
	Level of service	**E**	**E**
	Transit Level of Service		
	Transit travel speed, mi/h	10.5	10.2
	Transit LOS score	3.38	3.41
	Level of service	**C**	**C**

Exhibit 16-37
Example Problem 3:
Segment 5 Evaluation

Segment	Segment Evaluation Summary		
	Travel Direction	**Eastbound**	**Westbound**
Fifth Avenue to Sixth Avenue	***Basic Description***		
	Speed limit, mi/h	30	30
	Vehicle volume, veh/h	800	800
	Through lanes, ln	1	1
Segment length, ft 660	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	35.3	35.3
	Travel speed, mi/h	14.9	14.5
	Spatial stop rate, stops/mi	3.35	3.59
	Level of service	**D**	**D**
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	201.4	201.4
	Pedestrian travel speed, ft/s	3.18	3.18
	Pedestrian LOS score	2.87	2.87
	Level of service	**C**	**C**
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	No bicycle lane.	No bicycle lane.
	Bicycle LOS score	4.94	4.94
	Level of service	**E**	**E**
	Transit Level of Service		
	Transit travel speed, mi/h	6.2	14.5
	Transit LOS score	3.84	3.01
	Level of service	**D**	**C**

Exhibit 16-36 indicates that the vehicular through movements on Segment 1 in the eastbound and westbound travel directions have a travel speed of about 20 mi/h (i.e., about 53% of the base free-flow speed). LOS C applies to both movements. In contrast, Exhibit 16-37 indicates that the through movements have a travel speed of only about 15 mi/h on Segment 5 (or 42% of the base free-flow speed), which is LOS D. Vehicles stop at a rate of about 2.1 stops/mi on Segment 1 and about 3.5 stops/mi on Segment 5. Relative to Example Problem 1, conditions have degraded for vehicles traveling along these segments, but not enough to drop the LOS designation.

Pedestrian space on the sidewalk along the segment is generous on Segment 1 and adequate on Segment 5. These characterizations are based on Exhibit 16-11 and an assumed dominance of platoon flow for Segments 4 and 5. Pedestrians on these sidewalks can walk freely without having to alter their path to accommodate other pedestrians. Relative to Example Problem 1, the sidewalks are more distant from the traffic lanes, and crossing the street at a midsegment location is easier because of the raised-curb median. As a result, the pedestrian LOS is improved on all segments (i.e., from LOS D to C).

Bicycle lanes are not provided along the segment, so bicycle travel speed is not computed. The lack of a bicycle lane combined with a high traffic volume results in a bicycle LOS E for both directions of travel on Segment 1 and Segment 5. Relative to Example Problem 1, conditions have degraded for bicyclists on all segments, and the LOS for Segment 1 has dropped by one level. This reduction in service is due largely to the increased density of vehicles in the mixed traffic lanes.

Transit travel speed is about 10 mi/h on Segment 1 and corresponds to LOS C. On Segment 5, the travel speed is about 6 mi/h and 14 mi/h in the eastbound and westbound directions, respectively. The low speed for the eastbound direction results in LOS D. The higher speed for the westbound direction is due to the lack of a westbound transit stop on Segment 5. It results in LOS C. Relative to Example Problem 1 the slower travel speed has increased the transit LOS scores, but not enough to change the designated service level.

Facility Evaluation

The methodology described in Section 2 is used to compute the aggregate performance measures for each travel direction along the facility. The results are shown in Exhibit 16-38. This exhibit indicates that the vehicle travel speed is about 19 mi/h in each travel direction (or 50% of the base free-flow speed). An overall LOS C applies to both vehicular movements on the facility; however, it is noted that LOS D applies to Segments 4 and 5. Vehicles incur stops along the facility at a rate of about 2.3 stops/mi. Relative to Example Problem 1, vehicular LOS has degraded, but not enough to drop the LOS designation.

Exhibit 16-38
Example Problem 3: Facility Evaluation

	Facility Evaluation Summary		
	Travel Direction	**Eastbound**	**Westbound**
Facility length, ft 5,280	***Vehicle Level of Service***		
	Base free-flow speed, mi/h	36.8	36.8
	Travel speed, mi/h	18.7	18.5
	Spatial stop rate, stops/mi	2.23	2.33
	Level of service	**C**	**C**
	Poorest perf. segment LOS	D	D
	Pedestrian Level of Service		
	Pedestrian space, ft2/p	381.1	381.1
	Pedestrian travel speed, ft/s	3.4	3.4
	Pedestrian LOS score	2.88	2.88
	Level of service	**C**	**C**
	Poorest perf. segment LOS	C	C
	Bicycle Level of Service		
	Bicycle travel speed, mi/h	No bicycle lane.	No bicycle lane.
	Bicycle LOS score	4.76	4.76
	Level of service	**E**	**E**
	Poorest perf. segment LOS	E	E
	Transit Level of Service		
	Transit travel speed, mi/h	10.2	10.1
	Transit LOS score	3.37	3.38
	Level of service	**C**	**C**
	Poorest perf. segment LOS	D	D

Pedestrian space on the sidewalk along the facility is generous. Pedestrians on the sidewalks can walk freely without having to alter their path to accommodate other pedestrians. Increasing the separation between the sidewalk and traffic lanes and improving pedestrians' ability to cross the street (by adding a raised-curb median) result in an overall pedestrian LOS C for both directions of travel. This level compares favorably with the LOS D indicated in Example Problem 1.

Bicycle lanes are not provided along the facility, so bicycle travel speed is not computed. The lack of a bicycle lane combined with a high traffic volume results in an overall bicycle LOS E for both directions of travel. Conditions have degraded slightly, relative to Example Problem 1, but not enough to drop the LOS designation.

Transit travel speed is about 10 mi/h on the facility in each direction of travel. An overall LOS C is assigned to each direction. Conditions have degraded slightly, relative to Example Problem 1, but not enough to drop the transit LOS designation.

5. REFERENCES

These references are available in the Technical Reference Library in Volume 4.

1. Bonneson, J. A., M. P. Pratt, and M. A. Vandehey. *Predicting the Performance of Automobile Traffic on Urban Streets: Final Report.* National Cooperative Highway Research Program Project 3-79. Texas Transportation Institute, Texas A&M University, College Station, Jan. 2008.
2. Dowling, R. G., D. B. Reinke, A. Flannery, P. Ryus, M. Vandehey, T. A. Petritsch, B. W. Landis, N. M. Rouphail, and J. A. Bonneson. *NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets.* Transportation Research Board of the National Academies, Washington, D.C., 2008.
3. Kittelson & Associates, Inc.; KFH Group, Inc.; Parsons Brinckerhoff Quade and Douglass, Inc.; and K. Hunter-Zaworski. *TCRP Report 100: Transit Capacity and Quality of Service Manual*, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C., 2003.