CHAPTER 2
APPLICATIONS

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

OVERVIEW

Applications of the *Highway Capacity Manual* (HCM) range from the highly detailed to the highly generalized. The HCM can be applied to roadway system elements varying from individual points to an entire transportation system, to a number of travel modes that can be considered separately or in combination, and to several types of roadway and facility operating conditions. This chapter introduces the wide range of potential HCM applications. It also introduces the travel modes and roadway operating conditions to which the HCM can be applied.

HCM analysis levels.

The HCM can be applied at the *operational, design, preliminary engineering,* and *planning* analysis levels. The required input data typically remain the same at each analysis level, but the degree to which analysis inputs use default values instead of actual measured or forecast values differs. In addition, operational analyses and planning and preliminary engineering analyses frequently evaluate the level of service (LOS) that will result from a given set of inputs, whereas design analyses typically determine which facility characteristics will be needed to achieve a desired LOS.

Travel modes and roadway system elements addressed by the HCM.

The travel modes covered by the HCM include *motorized vehicles* [consisting of automobiles, light and heavy trucks, recreational vehicles (RVs), buses, and motorcycles], *pedestrians,* and *bicycles.* Some chapters also provide methods specific to *trucks* (e.g., single-unit trucks, tractor-trailers) and *public transit* vehicles operating on urban streets. The HCM's motorized vehicle methods assess the overall operation and quality of service of a traffic stream composed of a mix of vehicle types, while the truck and transit methods specifically address the operation (and, for transit, quality of service) of those modes.

From smallest to largest, roadway system elements include points, segments, facilities, corridors, areas, and systems.

All of these modes operate on a variety of roadway system elements, including *points* (e.g., intersections); *segments* (e.g., lengths of roadways between intersections); *facilities* (aggregations of points and segments); *corridors* (parallel freeway and arterial facilities); and, at the largest geographic scales, *areas* and *systems.*

HCM methodologies are provided both for *uninterrupted-flow* facilities, which have no fixed causes of delay or interruption external to the traffic stream, and for *interrupted-flow* facilities, on which traffic control devices such as traffic signals and STOP signs periodically interrupt the traffic stream. HCM analyses are applicable to *undersaturated* conditions (where demand is less than a roadway system element's capacity) and, in certain situations, to *oversaturated* conditions (where demand exceeds capacity).

Individual methodological chapters describe the extent to which the HCM can be used for oversaturated analyses. Chapter 6 describes alternative analysis tools that may be applied in situations in which the HCM cannot be used.

Finally, measures generated by HCM methodologies can be used for more than just stand-alone traffic analyses. This chapter describes potential applications of HCM methodologies to noise, air quality, economic, and multimodal planning analyses.

CHAPTER ORGANIZATION

Section 2 of this chapter describes the levels of analysis at which the HCM can be applied and introduces discussion of the analyst's need to balance the analysis objectives with the data requirements and computational complexity associated with different analysis levels and tools.

Section 3 defines the roadway system elements used by the HCM, introduces the service measures defining LOS for each system element, and provides guidance on applying HCM methods to a combined analysis of multiple facilities (e.g., corridors, areas, and systems).

Section 4 defines the travel modes for which the HCM provides analysis methods. Section 5 defines the types of operating conditions that can be observed on roadways. Section 6 discusses potential applications of HCM methods to support other kinds of analyses, such as air quality or noise analyses. Finally, Section 7 provides a list of references cited in this chapter.

RELATED HCM CONTENT

Other HCM content related to this chapter includes the following:

- Chapter 3, Modal Characteristics, which describes travel demand patterns associated with different modes, the types of transportation facilities used by these modes, and the interactions that occur between modes;
- Chapter 4, Traffic Operations and Capacity Concepts, which presents flow and capacity concepts by mode, along with operational performance measures that can be used to describe modal operations;
- Chapter 5, Quality and Level-of-Service Concepts, which presents measures that can be used to describe the service quality experienced by users of different modes;
- Chapter 6, HCM and Alternative Analysis Tools, which provides detailed guidance on matching potential analysis tools to analysis needs; and
- The *Planning and Preliminary Engineering Applications Guide to the HCM,* found in online Volume 4, which provides detailed guidance on applying HCM methods to the planning and preliminary engineering levels of analysis.

2. LEVELS OF ANALYSIS

OVERVIEW

Any given roadway operations analysis can be performed at different levels of detail, depending on the purpose of the analysis and the amount of information available. Typically, as an analysis becomes more detailed, its data requirements increase, the analysis area shrinks, the time requirements increase, and the degree of precision in the estimated performance improves (*1*).

In order of most to least detailed, the three primary levels of analysis used in the HCM are operational, design, and planning and preliminary engineering.

The HCM defines three primary levels of analysis. From the most to the least detailed, these are as follows:

- *Operational analysis* typically focuses on current or near-term conditions. It involves detailed inputs to HCM procedures, with no or minimal use of default values.
- *Design analysis* typically uses HCM procedures to identify the characteristics of a transportation facility that will allow it to operate at a desired LOS, with some use of default values.
- *Planning* and *preliminary engineering analyses* typically focus on initial problem identification, long-range analyses, and performance monitoring applications, where many facilities or alternatives must be evaluated quickly or when specific input values to procedures are not known. The extensive use of default values is required.

The typical usage of each of these analysis levels is described in the following subsections.

OPERATIONAL ANALYSIS

Operational analyses are applications of the HCM generally oriented toward current or near-term conditions. They aim at providing information for decisions on whether there is a need for improvements to an existing point, segment, or facility. Occasionally, an analysis is made to determine whether a more extensive planning study is needed. Sometimes the focus is on a network, or part of one, that is approaching oversaturation or an undesirable LOS: When, in the near term, is the facility likely to fail (or fail to meet a desired LOS threshold)? To answer this question, an estimate of the service flow rate allowable under a specified LOS is required.

The concept of LOS is described in Chapter 5, Quality and Level-of-Service Concepts.

HCM analyses also help practitioners make decisions about operating conditions. Typical alternatives often involve the analysis of appropriate lane configurations, alternative traffic control devices, signal timing and phasing, spacing and location of bus stops, frequency of bus service, and addition of a managed (e.g., high-occupancy vehicle) lane or a bicycle lane. The analysis produces operational measures for a comparison of the alternatives.

Because of the short-term focus of operational analyses, detailed inputs can be provided to the models. Many of the inputs may be based on field measurements of traffic, physical features, and control parameters. Generally, the use of default values at this level of analysis is inappropriate.

DESIGN ANALYSIS

Design analyses primarily apply the HCM to establish the detailed physical features that will allow a new or modified facility to operate at a desired LOS. Design projects are usually targeted for mid- to long-term implementation. Not all the physical features that a designer must determine are reflected in the HCM models. Typically, analysts using the HCM seek to determine such elements as the basic number of lanes required and the need for auxiliary or turning lanes. However, an analyst can also use the HCM to establish values for elements such as lane width, steepness of grade, length of added lanes, size of pedestrian queuing areas, widths of sidewalks and walkways, and presence of bus turnouts.

The data required for design analyses are fairly detailed and are based substantially on proposed design attributes. However, the intermediate- to long-term focus of the work will require use of some default values. This simplification is justified in part by the limits on the accuracy and precision of the traffic predictions with which the analyst is working.

PLANNING AND PRELIMINARY ENGINEERING ANALYSES

Planning analyses are applications of the HCM generally directed toward broad issues such as initial problem identification (e.g., screening a large number of locations for potential operations deficiencies), long-range analyses, and regional and statewide performance monitoring. An analyst often must estimate when the operation of the current and committed systems will fall below a desired LOS. Preliminary engineering analyses are often conducted to support planning decisions related to roadway design concept and scope and when alternatives analyses are performed. These studies can also assess proposed systemic policies, such as lane use control for heavy vehicles, systemwide freeway ramp metering and other intelligent transportation system applications, and the use of demand management techniques (e.g., congestion pricing) (2).

Planning and preliminary engineering analyses typically involve situations in which not all of the data needed for the analysis are available. Therefore, both types of analyses frequently rely on default values for many analysis inputs. Planning analyses may default nearly all inputs—for example, through the use of generalized service volume tables. Preliminary engineering analyses will typically fall between planning and design analyses in the use of default values.

Generalized service volume tables provide the maximum hourly or daily traffic volume that achieves a particular LOS, given a defined set of assumptions about a roadway's characteristics.

MATCHING THE ANALYSIS TOOL TO THE ANALYSIS LEVEL

Each methodological chapter in Volumes 2 and 3 has one core computational methodology. The degree to which defaulted or assumed values are used as inputs determines whether the HCM method is being applied at an operational, design, preliminary engineering, or planning level. However, the basic computational steps are the same regardless of the analysis level.

Some planning analyses (e.g., a long-range planning study where many input values, such as forecast volumes, are uncertain) may not require the level of precision provided by a core HCM methodology. Other kinds of planning analyses (e.g., sketch planning) may need to evaluate a large number of alternatives quickly. In either case, the analysis objective is to make a rough determination of whether a roadway facility will perform adequately rather than to estimate a particular performance characteristic, such as speed or delay, precisely. For these situations, the HCM and its companion *Planning and Preliminary Engineering Applications Guide to the HCM* (1) provide tools (e.g., service volume tables, quick estimation methods) that require less input data and fewer calculations, and they produce correspondingly less precise results.

Some operational analyses may require more detail (e.g., minute-by-minute roadway operations, evaluation of individual vehicle performance) than HCM methods are designed to produce. In other cases, a limitation of an HCM method may make its use inappropriate for a given analysis. In these situations, an analyst will need to apply an alternative analysis tool to complete the analysis.

Chapter 6, HCM and Alternative Analysis Tools, describes the range of HCM-based and alternative analysis tools available for analyzing roadway operations and quality of service and provides guidance on selecting an appropriate tool to meet a particular analysis need.

3. ROADWAY SYSTEM ELEMENTS

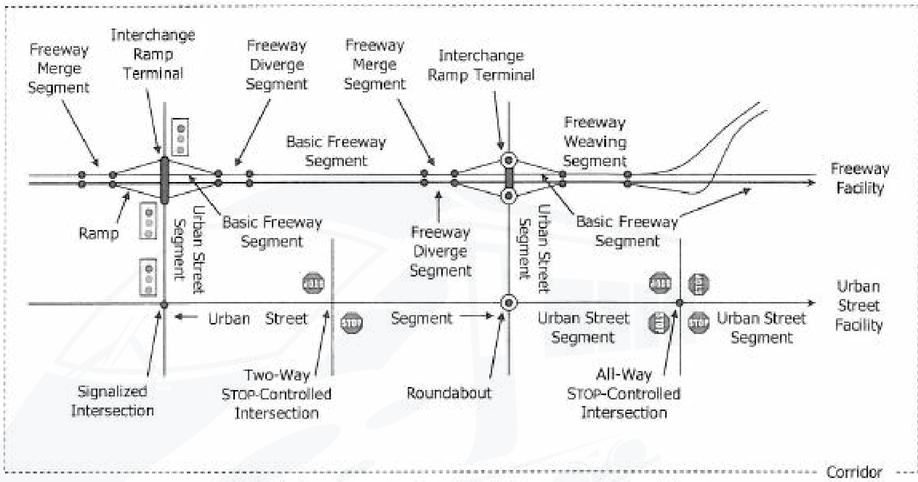
TYPES OF ROADWAY SYSTEM ELEMENTS

Of the six types of roadway system elements, the HCM focuses on points, segments, and facilities.

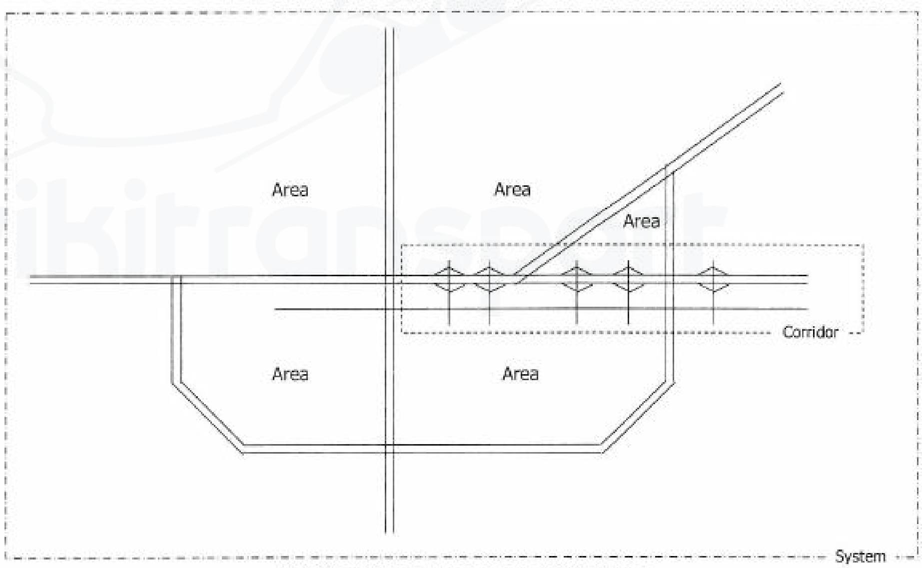
The HCM defines six main types of roadway system elements. From smallest to largest, the elements are points, segments, facilities, corridors, areas, and systems. The focus of the HCM is on the first three: points, segments, and facilities. Exhibit 2-1 illustrates the spatial relationships of these elements, and the following sections provide details about each system element type.

Exhibit 2-1
Illustrative Roadway System Elements

Note that a two-way STOP-controlled intersection does not normally divide the uncontrolled urban street into two segments.



(a) Points, Segments, Facilities, and Corridors



(b) Corridors, Areas, and Systems

Points

Points are places along a facility where (*a*) conflicting traffic streams cross, merge, or diverge; (*b*) a single traffic stream is regulated by a traffic control device; or (*c*) there is a significant change in the segment capacity (e.g., lane drop, lane addition, narrow bridge, significant upgrade, start or end of a ramp influence area).

Some points, such as interchange ramp terminals, may actually have a significant physical length associated with them, as suggested by Exhibit 2-1(a). For urban street facility analysis, points are treated as having zero length—all of the delay occurs at the point. For freeway facility analysis, points are used to define the endpoints of segments, but they have no associated performance measures or capacity, since these items are calculated at the segment level.

Freeway points are used only to define the endpoints of segments—performance measures and capacity are not defined for them.

Urban street points have a physical length but are treated as having zero length for facility analysis purposes.

Segments

A segment is the length of roadway between two points. Traffic volumes and physical characteristics generally remain the same over the length of a segment, although small variations may occur (e.g., changes in traffic volumes on a segment resulting from a low-volume driveway). Segments may or may not be directional. The HCM defines basic freeway and multilane highway segments, freeway weaving segments, freeway merge and diverge segments, two-lane highway segments, and urban street segments.

Facilities

Facilities are lengths of roadways, bicycle paths, and pedestrian walkways composed of a connected series of points and segments. Facilities may or may not be directional and are defined by two endpoints. The HCM defines freeway facilities, two-lane highway facilities, urban street facilities, and pedestrian and bicycle facilities.

The types of facilities addressed by the HCM are described in Chapter 3, Modal Characteristics.

Corridors

Corridors are generally a set of parallel transportation facilities designed to move people between two locations. For example, a corridor may consist of a freeway facility and one or more parallel urban street facilities. There may also be rail or bus transit service on the freeway, the urban streets, or both, and transit service could be provided within a separate, parallel right-of-way. Pedestrian or bicycle facilities may also be present within the corridor as designated portions of roadways and as exclusive, parallel facilities.

Areas

Areas consist of an interconnected set of transportation facilities serving movements within a specified geographic space as well as movements to and from adjoining areas. The primary factor distinguishing areas from corridors is that the facilities within an area need not be parallel to each other. Area boundaries can be set by significant transportation facilities, political boundaries, or topographic features such as ridgelines or major bodies of water.

Systems

Systems are composed of all the transportation facilities and modes within a particular region. A large metropolitan area typically has multiple corridors passing through it, which divide the system into a number of smaller areas. Each area contains a number of facilities, which, in turn, are composed of a series of points and segments. Systems can also be divided into modal subsystems (e.g., the roadway subsystem, the transit subsystem) and into subsystems composed of specific roadway elements (e.g., the freeway subsystem, the urban street subsystem).

ANALYSIS OF INDIVIDUAL SYSTEM ELEMENTS

Chapter 5, Quality and Level-of-Service Concepts, describes each system element's service measure(s).

The HCM provides tools to help analysts estimate performance measures for individual elements of a multimodal transportation system, as well as guidance on combining those elements to evaluate larger portions of the system. Exhibit 2-2 tabulates the various system elements for which the HCM provides analysis methodologies in Volumes 2 and 3, the service measure(s) used to determine LOS for each mode operating on each system element, and the HCM performance measure that can be used to aggregate results to a system level. Some combinations of system elements and travel modes unite several performance measures into a single traveler perception model that is used to generate a LOS score; the components of each model are listed in Exhibit 2-3.

Exhibit 2-2
HCM Service Measures by System Element and Mode

System Element	HCM Chapter	Service Measure(s) by Mode: Automobile	Pedestrian	Bicycle	Transit	Systems Analysis Measure
Freeway facility	10	Density	--	--	--	Speed
Basic freeway segment	12	Density	--	--	--	Speed
Multilane highway	12	Density	--	LOS score[a]	--	Speed
Freeway weaving segment	13	Density	--	--	--	Speed
Freeway merge and diverge segments	14	Density	--	--	--	Speed
Two-lane highway	15	Percent time-spent-following, speed	--	LOS score[a]	--	Speed
Urban street facility	16	Speed	LOS score[a]	LOS score[a]	LOS score[a]	Speed
Urban street segment	18	Speed	LOS score[a]	LOS score[a]	LOS score[a]	Speed
Signalized intersection	19	Delay	LOS score[a]	LOS score[a]	--	Delay
Two-way stop	20	Delay	Delay	--	--	Delay
All-way stop	21	Delay	--	--	--	Delay
Roundabout	22	Delay	--	--	--	Delay
Ramp terminal, alternative intersection	23	Experienced travel time	--	--	--	Travel time
Off-street pedestrian–bicycle facility	24	--	Space, events[b]	LOS score[a]	--	Speed

Notes: [a] See Exhibit 2-3 for the LOS score components.
[b] Events are situations where pedestrians meet bicyclists.

ASSESSMENT OF MULTIPLE FACILITIES

The analysis of a transportation system starts with estimates of delay at the point and segment levels. Point delays arise from the effects of traffic control devices such as traffic signals and STOP signs. Segment delays combine the point delay incurred at the end of the segment with other delays incurred within the segment. Examples of the latter include delays caused by midblock turning activity into driveways, parking activity, and midblock pedestrian crossings. The HCM estimates segment speed instead of segment delay; however, segment speed can be converted into segment delay by using Equation 2-1.

Exhibit 2-3
Components of Traveler-Perception Models Used in the HCM

System Element	HCM Chapter	Mode	Model Components
Multilane and two-lane highways	12, 15	Bicycle	Pavement quality, perceived separation from motor vehicles, motor vehicle volume and speed
Urban street facility	16	Automobile	Weighted average of segment automobile LOS scores
		Pedestrian	Urban street segment and signalized intersection pedestrian LOS scores, midblock crossing difficulty
		Bicycle	Urban street segment and signalized intersection bicycle LOS scores, driveway conflicts
		Transit	Weighted average of segment transit LOS scores
Urban street segment	18	Automobile	Stops per mile, left-turn lane presence
		Pedestrian	Pedestrian density, sidewalk width, perceived separation from motor vehicles, motor vehicle volume and speed
		Bicycle	Perceived separation from motor vehicles, pavement quality, motor vehicle volume and speed
		Transit	Service frequency, perceived speed, pedestrian LOS
Signalized intersection	19	Pedestrian	Street crossing delay, pedestrian exposure to turning vehicle conflicts, crossing distance
		Bicycle	Perceived separation from motor vehicles, crossing distance
Off-street pedestrian–bicycle facility	24	Bicycle	Average meetings/minute, active passings/minute, path width, centerline presence, delayed passings

The automobile traveler perception model for urban street segments and facilities is not used to determine LOS, but it is included to facilitate multimodal analyses.

Equation 2-1

$$D_i = AVO_i \times d_i \left(\frac{L_i}{S_i} - \frac{L_i}{S_{0i}}\right)$$

where

D_i = person-hours of delay on segment i,

AVO_i = average vehicle occupancy on segment i (passengers/vehicle),

d_i = vehicle demand on segment i (vehicles),

L_i = length of segment i (mi),

S_i = average vehicle speed on segment i (mi/h), and

S_{0i} = free-flow speed of segment i (mi/h).

Segment delays are added together to obtain facility estimates, and the sum of the facility estimates yields subsystem estimates. Mean delays for each subsystem are then computed by dividing the total person-hours of delay by the total number of trips on the subsystem. Subsystem estimates of delay can be combined into total system estimates, but typically the results for each subsystem are reported separately.

Typically, only the segments that constitute the collector and arterial system are used to estimate system delay.

SYSTEM PERFORMANCE MEASUREMENT

System performance must be measured in more than one dimension. When a single intersection is analyzed, computation of only the peak-period delay may suffice; however, when a system is analyzed, the geographic extent, the duration of delay, and any shifts in demand among facilities and modes must also be considered (*3*).

An increase in congestion on one system element may result in a shift of demand to other system elements. Therefore, estimating system delay is an iterative process. HCM techniques can be used to estimate the delay resulting from a given demand, but not the demand resulting from a given delay.

System performance can be measured in the following six dimensions:

Dimensions of system performance.

- *Quantity of service*—the number of person miles and person-hours provided by the system,
- *Intensity of congestion*—the amount of congestion experienced by users of the system,

- *Duration of congestion*—the number of hours that congestion persists,
- *Extent of congestion*—the physical length of the congested system,
- *Variability*—the day-to-day variation in congestion, and
- *Accessibility*—the percentage of the populace able to complete a selected trip within a specified time.

Quantity of Service

Quantity of service measures the utilization of the transportation system in terms of the number of people using the system, the distance they travel (person miles of travel, PMT), and the time they require to travel (person-hours of travel, PHT). Dividing the PMT by the PHT gives the mean trip speed for the system.

Intensity of Congestion

The intensity of congestion can be measured by using total person-hours of delay and mean trip speed. Other metrics, such as mean delay per person trip, can also be used. In planning and preliminary engineering applications, intensity of congestion is sometimes measured in terms of the volume-to-capacity ratio or the demand-to-capacity ratio.

Duration of Congestion

A segment is congested if the demand exceeds the segment's discharge capacity.

The duration of congestion is measured in terms of the maximum amount of time that congestion occurs anywhere in the system. A segment is congested if the demand exceeds the segment's discharge capacity. Transit subsystem congestion can occur either when the passenger demand exceeds the capacity of the transit vehicles or when the need to move transit vehicles exceeds the vehicular capacity of the transit facility.

Extent of Congestion

The extent of congestion may be expressed in terms of the directional miles of facilities congested or—more meaningfully for the public—in terms of the maximum percentage of system miles congested at any one time.

Variability

Variability of congestion is expressed by measures of travel time reliability, including measures of travel time variability and measures of a given trip's success or failure in meeting a target travel time. Section 2 of Chapter 4, Traffic Operations and Capacity Concepts, discusses travel time reliability in detail.

Accessibility

Accessibility examines the effectiveness of the system from a perspective other than intensity. Accessibility can be expressed in terms of the percentage of trips (or persons) able to accomplish a certain goal—such as going from home to work—within a targeted travel time. Accessibility can also be defined in terms of a traveler's ability to get to and use a particular modal subsystem, such as transit. This definition is closer to the Americans with Disabilities Act's use of the term.

4. TRAVEL MODES

This section introduces the four major travel modes addressed by the HCM: automobile, pedestrian, bicycle, and transit. Chapter 3, Modal Characteristics, provides details about each mode that are important for HCM analyses.

MOTORIZED VEHICLE MODE

The motorized vehicle mode includes all motor vehicle traffic using a roadway. Thus, automobiles, trucks, RVs, motorcycles, and public transit buses are all considered members of the motorized vehicle mode for HCM analysis purposes. Because different motor vehicle types have different operating characteristics (to be discussed further in Chapter 3), the HCM uses the passenger car as a common basis of comparison. For example, trucks take up more roadway space than passenger cars and accelerate more slowly, particularly on upgrades. Therefore, in some cases, the HCM converts trucks into passenger car equivalents (e.g., an average truck uses the same roadway space as two passenger cars on a freeway with a level grade); in other cases, parameters used by HCM methods are adjusted to reflect the specific mix of vehicles in the traffic stream.

The HCM's motorized vehicle mode methods assess the operations and quality of service of a traffic stream consisting of a mix of vehicle types.

Some HCM chapters also provide information specific to trucks and public transit, which are treated as separate modes in those cases.

The HCM's LOS thresholds for the motorized vehicle mode are based on the perspective of automobile drivers. Therefore, automobile LOS measures may not reflect the perspective of drivers of other types of motorized vehicles, especially trucks. The HCM defines a separate *transit mode* to present LOS measures for public transit passengers.

LOS measures for the motorized vehicle mode represent the perspective of automobile drivers. Separate LOS measures for the transit mode are used to represent the perspective of transit passengers.

Analytical methods and performance measures that specifically describe truck operations and quality of service are a growing area of research and transportation agency interest. This edition of the HCM occasionally uses a separate *truck mode* to present truck-specific information; however, in most cases, trucks are analyzed as part of the motorized vehicle mode.

PEDESTRIAN MODE

The pedestrian mode consists of travelers along a roadway or pedestrian facility making a journey (or at least part of their journey) on foot. Pedestrians walk at different speeds, depending on their age, their ability, and environmental characteristics (e.g., grades and climate); HCM procedures generally account for this variability. Sidewalks and pathways may be used by more than just foot-based traffic—for example, inline skaters and persons in wheelchairs—but the HCM's LOS thresholds reflect the perspective of persons making a walking journey.

BICYCLE MODE

The bicycle mode consists of travelers on a roadway or pathway who are using a nonmotorized bicycle for their trip; bicycle LOS thresholds reflect their perspective. Mopeds and motorized scooters are not considered bicycles for HCM analysis purposes.

The companion TCQSM provides capacity and speed estimation procedures for transit vehicles and additional LOS measures for transit passengers.

TRANSIT MODE

Urban roadways are often shared with public transit buses and, occasionally, with rail transit vehicles such as streetcars and light rail vehicles. The HCM's urban street facility and segment chapters (Chapters 16 and 18) provide methods for assessing the quality of service of transit service from the passenger point of view. The companion *Transit Capacity and Quality of Service Manual* (TCQSM) (4) provides methods for assessing the capacity, speed, and quality of service of a variety of transit modes in both on- and off-street settings.

5. OPERATING CONDITIONS

The HCM provides methods for analyzing traffic flow under a variety of conditions. These conditions are introduced and defined in this section, since they are used repeatedly throughout the HCM. They are described more fully in Chapter 4, Traffic Operations and Capacity Concepts.

UNINTERRUPTED FLOW

Uninterrupted-flow facilities have no fixed causes of delay or interruption external to the traffic stream.

Uninterrupted-flow facilities have no fixed causes of delay or interruption external to the traffic stream. Volume 2 of the HCM provides analysis methodologies for uninterrupted-flow facilities.

Freeways and their components operate under the purest form of uninterrupted flow. There are no fixed interruptions to traffic flow, and access is controlled and limited to ramp locations. Multilane highways and two-lane highways can also operate under uninterrupted flow in long segments between points of fixed interruption. On multilane and two-lane highways, points of fixed interruption (e.g., traffic signals) as well as uninterrupted-flow segments must often be examined.

The traffic stream on uninterrupted-flow facilities is the result of individual vehicles interacting with each other and the facility's geometric characteristics. The pattern of flow is generally controlled only by the characteristics of the land uses that generate traffic using the facility, although freeway management and operations strategies—such as ramp metering, freeway auxiliary lanes, truck lane restrictions, variable speed limits, and incident detection and clearance—can influence traffic flow. Operations can also be affected by environmental conditions, such as weather or lighting; by pavement conditions; by work zones; and by the occurrence of traffic incidents (*5*, *6*).

Uninterrupted flow describes the type of facility, not the quality of the traffic flow at any given time. The terms *oversaturated* and *undersaturated flow*, described below, reflect the quality of traffic flow. An oversaturated freeway is still an uninterrupted-flow facility because the causes of congestion are internal.

INTERRUPTED FLOW

Interrupted-flow facilities have fixed causes of periodic delay or interruption to the traffic stream, such as traffic signals, roundabouts, and STOP signs.

Interrupted-flow facilities have fixed causes of periodic delay or interruption to the traffic stream, such as traffic signals, roundabouts, and STOP signs. Urban streets are the most common form of this kind of facility. Exclusive pedestrian and bicycle facilities are also treated as interrupted flow, since they may occasionally intersect other streets at locations where pedestrians and bicyclists do not automatically receive the right-of-way. Volume 3 of the HCM provides analysis methodologies for interrupted-flow facilities.

The traffic flow patterns on an interrupted-flow facility are the result not only of vehicle interactions and the facility's geometric characteristics but also of the traffic control used at intersections and the frequency of access points to the facility. Traffic signals, for example, allow designated movements to occur only during certain portions of the signal cycle (and, therefore, only during certain portions of an hour). This control creates two significant outcomes. First, time becomes a factor affecting flow and capacity because the facility is not available for continuous use. Second, the traffic flow pattern is dictated by the type of control used. For instance, traffic signals create platoons of vehicles that travel along the facility as a group, with significant gaps between one platoon and the next. In contrast, all-way STOP-controlled intersections and roundabouts discharge vehicles more randomly, creating small (but not necessarily usable) gaps in traffic at downstream locations (*5, 7*).

UNDERSATURATED FLOW

Traffic flow during an analysis period (e.g., 15 min) is specified as *undersaturated* when the following conditions are satisfied: (*a*) the arrival flow rate is lower than the capacity of a point or segment, (*b*) no residual queue remains from a prior breakdown of the facility, and (*c*) traffic flow is unaffected by downstream conditions.

Free-flow speed is the average speed of traffic on a segment as volume and density approach zero.

Uninterrupted-flow facilities operating in a state of undersaturated flow will typically have travel speeds within 10% to 20% of the facility's free-flow speed, even at high flow rates, under base conditions (e.g., level grades, standard lane widths, good weather, no incidents). Furthermore, no queues would be expected to develop on the facility.

On interrupted-flow facilities, queues form as a natural consequence of the interruptions to traffic flow created by traffic signals and STOP and YIELD signs. Therefore, travel speeds are typically 30% to 65% below the facility's free-flow speed in undersaturated conditions. Individual cycle failures—where a vehicle has to wait through more than one green phase to be served—may occur at traffic signals under moderate- to high-volume conditions as a result of natural variations in the cycle-to-cycle arrival and service rate. Similarly, STOP- and YIELD-controlled approaches may experience short periods of significant queue buildup. However, as long as all of the demand on an intersection approach is served within a 15-min analysis period, including any residual demand from the prior period, the approach is considered to be undersaturated.

OVERSATURATED FLOW

Traffic flow during an analysis period is characterized as *oversaturated* when any of the following conditions is satisfied: (*a*) the arrival flow rate exceeds the capacity of a point or segment, (*b*) a queue created from a prior breakdown of a facility has not yet dissipated, or (*c*) traffic flow is affected by downstream conditions.

On uninterrupted-flow facilities, oversaturated conditions result from a bottleneck on the facility. During periods of oversaturation, queues form and extend backward from the bottleneck point. Traffic speeds and flows drop significantly as a result of turbulence, and they can vary considerably, depending on the severity of the bottleneck. Freeway queues differ from queues at undersaturated signalized intersections in that they are not static or "standing." On freeways, vehicles move slowly through a queue, with periods of stopping and movement. Even after the demand at the back of the queue drops, some time is required for the queue to dissipate because vehicles discharge from the queue at a slower rate than they do under free-flow conditions. Oversaturated conditions persist within the queue until the queue dissipates completely after a period of time during which demand flows are less than the capacity of the bottleneck.

On interrupted-flow facilities, oversaturated conditions generate a queue that grows backward from the intersection at a rate faster than can be processed by the intersection over the analysis period. Oversaturated conditions persist after demand drops below capacity until the residual queue (i.e., the queue over and above what would be created by the intersection's traffic control) has dissipated. A queue generated by an oversaturated unsignalized intersection dissipates more gradually than is typically possible at a signalized intersection.

If an intersection approach or ramp meter cannot accommodate all of its demand, queues may back into upstream intersections and adversely affect their performance. Similarly, if an interchange ramp terminal cannot accommodate all of its demand, queues may back onto the freeway and adversely affect the freeway's performance.

QUEUE DISCHARGE FLOW

A third type of flow, queue discharge flow, is particularly relevant for uninterrupted-flow facilities. Queue discharge flow represents traffic flow that has just passed through a bottleneck and, in the absence of another bottleneck downstream, is accelerating back to the facility's free-flow speed. Queue discharge flow is characterized by relatively stable flow as long as the effects of another bottleneck downstream are not present.

On freeways, this flow type is typically characterized by speeds ranging from 35 mi/h up to the free-flow speed of the freeway segment. Lower speeds are typically observed just downstream of the bottleneck. Depending on horizontal and vertical alignments, queue discharge flow usually accelerates back to the facility's free-flow speed within 0.5 to 1 mi downstream of the bottleneck. The queue discharge flow rate from the bottleneck is lower than the maximum flows observed before breakdown; this effect is discussed further in Section 2 of Chapter 10, Freeway Facilities Core Methodology.

6. HCM ANALYSIS AS PART OF A BROADER PROCESS

Since its first edition in 1950, the HCM has provided transportation analysts with tools for estimating traffic operational measures such as speed, density, and delay. It also has provided insights and specific tools for estimating the effects of traffic, roadway, and other conditions on the capacity of facilities. Over time, calculated values from the HCM have increasingly been used in other transportation work. The use of estimated or calculated values from HCM work as the foundation for estimating user costs and benefits in terms of economic value and environmental changes (especially air and noise) is particularly pronounced in transportation priority programs and in the justification of projects. This section provides examples of how HCM outputs can be used as inputs to other types of analyses.

NOISE ANALYSIS

At the time this chapter was written, federal regulations specifying noise abatement criteria stated that "in predicting noise levels and assessing noise impacts, traffic characteristics which will yield the worst hourly traffic noise impact on a regular basis for the design year shall be used" [23 CFR 772.17(b)]. The "worst hour" is usually taken to mean the loudest hour, which does not necessarily coincide with the busiest hour, since vehicular noise levels are directly related to speed. Traffic conditions in which large trucks are at their daily peak and in which LOS E conditions exist typically represent the loudest hour (*8*).

AIR QUALITY ANALYSIS

The 1990 Clean Air Act Amendments required state and local agencies to develop accurate emission inventories as an integral part of their air quality management and transportation planning responsibilities. Vehicular emissions are a significant contributor to poor air quality; therefore, the U.S. Environmental Protection Agency (EPA) has developed analysis procedures and tools for estimating emissions from mobile sources such as motorized vehicles. One input into the emissions model is average vehicle speed, which can be entered at the link (i.e., length between successive ramps) level, if desired. EPA's model is sensitive to average vehicle speed (i.e., a 20% change in average vehicle speed resulted in a greater than 20% change in the emissions estimate), which implies that accurate speed inputs are a requirement for accurate emissions estimates. The HCM is a tool recommended by EPA for generating speed estimates on freeways and arterials and collectors (*9–11*).

ECONOMIC ANALYSIS

The economic analysis of transportation improvements also depends to a large extent on information generated from the HCM. Road user benefits are directly related to reductions in travel time and delay, while costs are determined from construction of roadway improvements (e.g., addition of lanes, installation of traffic signals) and increases in travel time and delay. The following excerpt from the American Association of State Highway and Transportation Officials Green Book (*12*, p. 3-2) indicates the degree to which such analyses depend on the HCM:

> The [HCM] provides many tools and procedures to assist in the calculation of segment speeds. These procedures permit detailed consideration of segment features, including the effects of road geometry and weaving on the capacity and speed of a highway segment. Speed can be calculated for local streets and roads, highways and freeways using the [HCM]. The most accurate rendering of the effects of additional lanes on speed, therefore, is through the use of the [HCM] calculation procedures.

MULTIMODAL PLANNING ANALYSIS

An increasing number of jurisdictions are taking an integrated approach to multimodal transportation planning. That is, rather than developing plans for the automobile, transit, and pedestrian and bicycle modes in isolation, these jurisdictions evaluate trade-offs among the modes as part of their transportation planning and decision making. The HCM 2010 is designed to support those efforts. For example, Chapter 16, Urban Street Facilities, presents an integrated, multimodal set of LOS measures for urban streets. The other interrupted-flow chapters in Volume 3 also integrate pedestrian and bicycle measures, to the extent that research is available to support those measures.

SYSTEM PERFORMANCE MEASUREMENT

State and federal governments use HCM procedures in reporting transportation system performance. For example, the Federal Highway Administration's Highway Performance Monitoring System uses HCM procedures to estimate the capacity of highway sections and to determine volume-to-service flow ratios (*13*). In addition, the federal surface transportation funding act, the Moving Ahead for Progress in the 21st Century Act, established performance-based procedures for planning and project programming (*14*), and performance measures that the HCM can estimate are anticipated to play a role in these performance monitoring activities. Florida uses HCM procedures to estimate speeds on the state highway system as part of its mobility performance measures reporting.

SUMMARY

In summary, almost all economic analyses and all air and noise environmental analyses rely directly on one or more measures estimated or produced with HCM calculations. Exhibit 2-4 lists the motorized vehicle–based performance measures from this manual that are applicable to environmental or economic analyses.

Exhibit 2-4
HCM Motorized Vehicle Performance Measures for Environmental and Economic Analyses

Chapter	Motorized Vehicle Performance Measure	Analysis Types Appropriate for Use: Air	Noise	Economic
10. Freeway Facilities Core Methodology	Density[a]			
	Vehicle hours of delay			√
	Speed	√	√	√
	Travel time			√
12. Basic Freeway and Multilane Highway Segments	Density[a]			
	Speed	√	√	√
	v/c ratio	√		√
13. Freeway Weaving Segments	Density[a]			
	Weaving speed	√	√	√
	Nonweaving speed	√	√	√
14. Freeway Merge and Diverge Segments	Density[a]			
	Speed	√	√	√
15. Two-Lane Highways	Percent time-spent-following[a]			
	Speed[a]	√	√	√
16. Urban Street Facilities 18. Urban Street Segments	Speed[a]			
	Stop rate	√	√	√
	Running time	√		√
	Intersection control delay	√		√
19. Signalized Intersections 20. TWSC Intersections 21. AWSC Intersections 22. Roundabouts	Control delay[a]	√		√
	v/c ratio	√		√
23. Ramp Terminals and Alternative Intersections	Extra distance travel time[a]	√		√
	v/c ratio	√		√

Notes: [a] Chapter service measure.
TWSC = two-way STOP-controlled, AWSC = all-way STOP-controlled, *v/c* = volume to capacity.

7. REFERENCES

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

1. Dowling, R., P. Ryus, B. Schroeder, M. Kyte, and T. Creasey. *NCHRP Report 825: Planning and Preliminary Engineering Applications Guide to the HCM.* Transportation Research Board of the National Academies, Washington, D.C., 2016.
2. *Florida Quality/Level of Service Handbook.* Systems Planning Office, Florida Department of Transportation, Tallahassee, 2009.
3. Lomax, T., S. Turner, G. Shunk, H. S. Levinson, R. H. Pratt, P. N. Bay, and G. B. Douglas. *NCHRP Report 398: Quantifying Congestion.* Transportation Research Board, National Research Council, Washington, D.C., 1997.
4. Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc.; Texas A&M Transportation Institute; and Arup. *TCRP Report 165: Transit Capacity and Quality of Service Manual,* 3rd ed. Transportation Research Board of the National Academies, Washington, D.C., 2013.
5. McShane, W. R., and R. P. Roess. *Traffic Engineering.* Prentice Hall, Englewood Cliffs, N.J., 1990.
6. Neudorff, L. G., J. E. Randall, R. Reiss, and R. Gordon. *Freeway Management and Operations Handbook.* Office of Transportation Management, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., Sept. 2003 (updated June 2006).
7. Robinson, B. W., L. Rodegerdts, W. Scarbrough, W. Kittelson, R. Troutbeck, W. Brilon, L. Bondzio, K. Courage, M. Kyte, J. Mason, A. Flannery, E. Myers, J. Bunker, and G. Jacquemart. *Roundabouts: An Informational Guide.* Report FHWA-RD-00-067. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., June 2000.
8. Cohn, L. F., R. A. Harris, and P. R. Lederer. Chapter 8: Environmental and Energy Considerations. In *Transportation Planning Handbook,* 2nd ed. (J. D. Edwards, Jr., ed.), Institute of Transportation Engineers, Washington, D.C., 1999.
9. Decker, S., J. Suhrbier, K. Rhoades, H. Weinblat, G. Brooks, and E. Dickson. Volume IV, Chapter 2: Use of Locality-Specific Transportation Data for the Development of Mobile Source Emission Inventories. In *Procedures for Emission Inventory Preparation,* U.S. Environmental Protection Agency, Washington, D.C., Sept. 1996.
10. Giannelli, R. A., J. H. Gilmore, L. Landman, S. Srivastava, M. Beardsley, D. Brzezinski, G. Dolce, J. Koupal, J. Pedelty, and G. Shyu. *Sensitivity Analysis of MOBILE6.0.* Assessment and Standards Division, U.S. Environmental Protection Agency, Washington, D.C., Dec. 2002.
11. *Technical Guidance on the Use of MOBILE6.2 for Emission Inventory Preparation.* Transportation and Regional Programs Division, U.S. Environmental Protection Agency, Washington, D.C., Aug. 2004.

12. *A Policy on Geometric Design of Highways and Streets*, 5th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.

13. Federal Highway Administration. *HPMS Field Manual.* Appendix N: Procedures for Estimating Highway Capacity. http://www.fhwa.dot.gov/ohim/hpmsmanl/appn.cfm. Accessed Aug. 27, 2009.

14. Federal Highway Administration. *Moving Ahead for Progress in the 21st Century Act (MAP-21): A Summary of Highway Provisions.* Office of Policy and Governmental Affairs, Washington, D.C., July 17, 2012. http://www.fhwa.dot.gov/map21/docs/map21_summary_hgwy_provisions.pdf. Accessed May 21, 2015.