CHAPTER 8
HCM PRIMER

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

OVERVIEW

The *Highway Capacity Manual 2010* (HCM) is the fifth edition of this fundamental reference document. Its objectives are threefold:

1. To define performance measures and describe survey methods for key traffic characteristics,
2. To provide methodologies for estimating and predicting traffic-related performance measures, and
3. To explain methodologies in a manner that allows readers to understand the factors that affect multimodal roadway operations.

The travel modes covered by the HCM consist of the *motorized vehicle, pedestrian,* and *bicycle* modes, as well as *public transit* service in a multimodal context. The motorized vehicle mode includes motorcycles; light vehicles such as automobiles and sport-utility vehicles; and heavy vehicles such as trucks, recreational vehicles, and buses.

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

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

HCM methodologies can be applied both to *uninterrupted-flow* roadways, such as freeways, multilane rural highways, and two-lane rural highways, and to *interrupted-flow* roadways, primarily urban streets and the intersections located along those streets. Methodologies are also provided for evaluating off-street pedestrian and bicycle facilities. The HCM can be applied to *undersaturated* conditions (where traffic demand is less than a roadway's capacity) and, in certain situations, to *oversaturated* conditions (where demand exceeds capacity).

The HCM presents the best available techniques at the time of publishing for determining roadway capacity and level of service (LOS) that have been proved to work in the United States and validated by a group of independent experts. However, the HCM does not endeavor to establish a legal standard for highway design or construction.

CHAPTER PURPOSE AND ORGANIZATION

Chapter 8 is written for a nontechnical audience and is a synopsis of Volume 1 of the HCM.

This chapter is written for an audience (e.g., decision makers) who may be regularly presented with the results of HCM analyses and who may have no formal training in transportation engineering, but who need to understand basic HCM concepts, terminology, and methodological strengths and weaknesses in making informed decisions. This chapter addresses the following:

- Section 2 covers basic traffic operations terminology and concepts.
- Section 3 presents concepts related to quality of service (how well a transportation facility or service operates from a traveler's perspective).
- Section 4 describes the different levels of analysis that can be performed with the HCM and provides guidance on selecting an analysis tool and interpreting and presenting the results from an HCM analysis.
- Section 5 discusses companion documents to the HCM and issues to consider when the HCM is used in a decision-making process.

The HCM can be applied at the planning, preliminary engineering, operations, and design levels of analysis.

2. HIGHWAY OPERATIONS CONCEPTS

This section introduces basic traffic engineering concepts that form the foundation of technical analyses that apply the HCM or other analysis tools. The section describes the two main types of traffic flow analyzed by the HCM—uninterrupted flow (e.g., freeways) and interrupted flow (e.g., urban streets)—along with their characteristics, the HCM methodologies available for analyzing them, and key performance measures produced by these analyses. This section also summarizes how the different travel modes using a roadway interact with each other and how they affect the roadway's overall operation.

CAPACITY AND TRAFFIC FLOW CONCEPTS

Capacity Definition

Capacity is the maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions. This one-sentence definition covers a variety of diverse topics, each discussed below:

- *Roadway conditions* include the number and width of lanes, shoulder width, and the roadway's horizontal and vertical alignment. Substandard lane and shoulder widths result in a permanently lower capacity than could be achieved with standard widths. Work zones and incidents (e.g., stalls, crashes) that close or block travel lanes or shoulders reduce roadway capacity temporarily, but their effects can last much longer than the actual work zone or incident event.
- *Environmental conditions* include weather and lighting. The HCM assumes good weather as a base but also provides guidance on evaluating the impact of inclement weather on roadway operations—for example, as part of an analysis of travel time reliability.
- *Traffic conditions* include the proportion of heavy vehicles (e.g., trucks) in the traffic stream, the proportion of roadway users who are regular users, turning-movement patterns at intersections, and the distribution of vehicles between lanes and directions of a roadway.
- *Control conditions* include the types of traffic control used at intersections (i.e., traffic signals, STOP signs, or YIELD signs), the amount of green time allocated to a particular movement at a traffic signal, and restrictions on the use of certain lanes (e.g., part-time restrictions on parking, truck prohibitions in the left lane of a freeway).

In comparison with passenger cars, heavy vehicles take up more roadway space and have poorer operating characteristics.

As traffic flow approaches a roadway's capacity, traffic speeds decrease and—on uninterrupted-flow roadways—vehicles follow each other at closer headways. When traffic demand exceeds the roadway's capacity, a breakdown occurs, as evidenced by sharply decreased travel speeds and a growing queue of vehicles.

Reasonable expectancy is the basis for defining capacity. A given system element's capacity is a volume or flow rate that can be achieved repeatedly under the same prevailing conditions, as opposed to being the maximum value that might ever be observed. Since the prevailing conditions (e.g., weather, mix of heavy vehicles) will vary within the day or from one day to the next, a system element's capacity at a given point in time will also vary—a traffic flow that can be served at one point in time may result in a breakdown at a different time.

Base Capacity and Actual Capacity

The base capacity values presented in the HCM—for example, 2,400 vehicles per hour per lane on a freeway with a 75-mph free-flow speed, or 1,900 vehicles per hour of green at a traffic signal—are just that: *base values.* These values incorporate, among other factors, ideal roadway geometry, a traffic stream composed entirely of passenger cars, and good weather. To the extent that conditions vary from the ideal—truck presence, an upgrade, constrained shoulder width, nonfamiliar roadway users, or severe weather, for example—actual capacity will be reduced from the base value. Driver characteristics (e.g., willingness to tolerate close headways) may vary locally, and the HCM provides a means of calibrating its methods to account for local conditions.

The HCM's base capacity values represent ideal conditions; HCM methods reduce capacity to reflect nonideal conditions. HCM methods can also be calibrated to account for local conditions.

Volume and Flow Rate

HCM analyses typically evaluate the peak 15 minutes of an analysis hour. Traffic demands usually fluctuate over the course of an hour, so a roadway that could theoretically accommodate a given *hourly volume* of evenly arriving vehicles may break down when a shorter-term peak in demand occurs. The effects of a breakdown can extend far beyond the time during which demand exceeded capacity, can take several hours to dissipate, and may spread well beyond the original point of breakdown. The HCM addresses this peaking phenomenon by using *flow rates* that represent the equivalent hourly volume that would be observed if the peak 15-minute demand was sustained over an entire hour. A 15-minute analysis period accommodates most variations in flow without producing an excessively conservative estimate of capacity.

Traffic demands used in HCM analyses are typically expressed as flow rates *that represent four times the peak 15-minute traffic demand.*

Volume and Demand

Volume and flow rate help quantify *demand,* that is, the number of users (e.g., vehicles, persons) who *desire* to use a given portion of roadway during a specific time period, typically 1 hour or 15 minutes. Traffic volumes observed in the field may not reflect actual demand, because capacity constraints upstream of the count location may limit the number of vehicles that *can* reach the count location.

Demand relates to the number of vehicles that would like to be served by a roadway element, while volume relates to the number that are actually served.

Demand is typically the desired input to HCM analyses. (An exception might be the analysis of traffic conditions beyond a bottleneck that is not planned to be removed.) Only when conditions are *undersaturated* (i.e., demand is less than capacity) and no upstream bottlenecks exist can demand at a location be assumed equivalent to the measured volume at that location. Where bottlenecks exist, neglecting to use demand as an input to an HCM method will produce results that underestimate the presence and extent of congestion. In other words, using observed volumes instead of demand will likely result in inaccurate HCM results.

Vehicle Capacity and Person Capacity

Persons per hour, passenger car equivalents per hour, and vehicles per hour are all measures that can define capacity. The concept of person flow is important (*a*) in making strategic decisions about transportation modes in heavily traveled corridors and (*b*) in defining the role of transit and high-occupancy-vehicle priority treatments. Person capacity and person flow weight each vehicle type in the traffic stream by the number of occupants carried.

UNINTERRUPTED-FLOW ROADWAYS

Characteristics

Uninterrupted-flow roadways have no fixed causes of delay or interruptions to the traffic stream such as traffic signals. 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; however, examination of points along those highways where traffic may need to slow or stop (e.g., intersections where the highway is controlled by traffic signals, STOP signs, or YIELD signs) may also be necessary.

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 the 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; and by the occurrence of traffic incidents (*1*, *2*).

"Uninterrupted flow" describes the type of facility, not the quality of the traffic flow at any given time. A freeway experiencing stop-and-go congestion, for example, is still an uninterrupted-flow facility, despite the congestion.

HCM Methodologies

The HCM provides methodologies for the following uninterrupted-flow roadway elements:

- *Freeway facilities.* An extended length of a single freeway composed of a set of connected basic freeway, weaving, and merge and diverge segments.
- *Basic freeway segments.* The portions of a freeway outside the influence area of any on- or off-ramps.
- *Freeway weaving segments.* The portions of a freeway where an on-ramp is closely followed by an off-ramp and entering or exiting traffic must make at least one lane change to enter or exit the freeway.

- *Freeway merge and diverge segments.* The portions of a freeway where traffic enters or exits without having to change lanes to enter or leave a through traffic lane.
- *Multilane highways.* Higher-speed facilities, with two or more lanes in each direction, without full access control (i.e., traffic can enter or exit via at-grade intersections, which may or may not be signal-controlled).
- *Two-lane highways.* Facilities with mostly one lane of travel per direction, with motorists using passing lanes, turnouts, or the opposing lane (where allowed by regulation and opposing traffic) to pass slower vehicles.

Performance Measures

The following are key performance measures produced by the HCM that can be used to evaluate the operation of uninterrupted-flow roadways:

- *Density* is typically defined by the average number of vehicles (or passenger car equivalents) per lane mile of roadway. The denser the traffic conditions, the closer vehicles are to each other and the harder it is for vehicles to change lanes or maintain a constant speed. Density is frequently used to evaluate freeways and multilane highways.
- *Speed* reflects how fast motorists can travel. The speed at which a motorist would travel along an uninterrupted-flow roadway under low-volume conditions is known as the *free-flow speed.* Drivers experience *delay* when their travel speed is less than the free-flow speed, which is a result of traffic demands approaching or exceeding the roadway's capacity. Speed is used to evaluate all kinds of uninterrupted-flow roadways.
- *Travel time reliability* measures reflect the consistency (or lack thereof) of travel times or speeds over a long time frame (e.g., a year). Reliability measures provide an important contrast to traditional traffic operations performance measures that report average conditions; reliability measures indicate the range of possible conditions that may occur, which may differ considerably from the average condition.
- *Percent time-spent-following* is a measure specific to two-lane highways. It represents the freedom to maneuver and the comfort and convenience of travel. It is the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of the inability to pass.
- *Volume-to-capacity (v/c) ratio* reflects how closely a roadway is operating to its capacity. By definition, the volume of traffic using a roadway cannot exceed the roadway's capacity. Therefore, the *v/c* ratio is actually a *demand-to-capacity (d/c)* ratio. However, *v/c* ratio is the historically used term. A *v/c* ratio that exceeds 1.00 indicates that more vehicles demand to use a roadway than can be accommodated.

INTERRUPTED-FLOW ROADWAYS

Characteristics

Interrupted-flow facilities have fixed causes of periodic delay or traffic stream interruption, 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 are not automatically granted the right-of-way.

The traffic flow patterns on an interrupted-flow facility are the result of vehicle interactions, the facility's geometric characteristics, 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 affects flow and capacity, since 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 (*1*, *3*).

HCM Methodologies

The HCM provides methodologies for the following roadway elements:

- *Urban street facilities,* which are extended sections of roadway whose operation is strongly influenced by traffic signals or other traffic control. Facilities are formed by two or more consecutive *urban street segments,* typically street sections from one traffic signal to the next. Roundabouts and STOP-sign control on the urban street can also define the end of a segment. Segments are the basic analysis unit for multimodal analyses.
- *Signalized intersections.*
- *Interchange ramp terminals,* which are two closely spaced intersections of freeway ramps and surface streets, where the management of queues between the two intersections is a key concern.
- *Alternative intersections,* where one or more turning movements are rerouted to secondary intersections. Examples include median U-turn, restricted crossing U-turn, and displaced left-turn intersections.
- *Unsignalized intersections,* including two-way STOP-controlled intersections (i.e., intersections where only the side-street approaches are required to stop), all-way STOP-controlled intersections, and roundabouts.
- *Off-street pedestrian and bicycle facilities,* such as bicycle paths or multiuse trails. On-street pedestrian and bicycle facilities are addressed by the methodologies for urban streets and intersections, although not every system element has an associated pedestrian or bicycle methodology.

Performance Measures

The following are key performance measures generated by the HCM for evaluating the operation of motorized vehicles on interrupted-flow roadways:

- *Control delay* is the delay incurred because of the presence of a traffic control device. It includes delay associated with vehicles slowing in advance of an intersection, the time spent stopped on an intersection approach, the time spent as vehicles move through a queue, and the time needed for vehicles to accelerate to their desired speed once through the intersection.
- *Speed* reflects how fast motorists can traverse a roadway section, including the effects of traffic control devices, delays due to turning vehicles at intersections and driveways, and traffic demands on the roadway.
- *Number of stops* reflects how frequently motorists must come to a stop as they travel along an urban street because of traffic control, turning vehicles, midblock pedestrian crossings, and similar factors.
- *Queue length* reflects how far traffic backs up as a result of traffic control (e.g., a queue from a traffic signal) or a vehicle stopped in the travel lane while waiting to make a turn. Queuing is both an important operational measure and a design consideration—queues that are longer than the available storage length can create several types of operational problems. A through-lane queue that extends past the entrance to a turn lane blocks access to the turn lane and keeps it from being used effectively. Similarly, a turn-lane queue overflow into a through lane interferes with the movement of through vehicles. Queues that extend upstream from an intersection can block access into and out of driveways and—in a worst case—can spill back into and block upstream intersections, causing side streets to begin to queue back.
- *Volume-to-capacity (demand-to-capacity) ratios,* whose definition and use are similar to those of uninterrupted-flow roadways.
- *Travel time reliability* measures reflect the consistency (or lack thereof) of travel times or speeds over a long time frame (e.g., a year). As is the case with uninterrupted-flow roadways, reliability measures provide an important contrast to traditional traffic operations performance measures by indicating the range of possible conditions that may occur over a long time frame rather than the average condition during that period.
- The performance measures produced by *traveler perception models* describe how travelers would perceive conditions. These models use a variety of inputs to generate a single performance measure. The measure value predicts the average perception rating that all users of a given mode would give a particular system element. Traveler perception models are frequently applied to pedestrian, bicycle, and transit analyses and are discussed further in Section 3, Quality and Level-of-Service Concepts.
- *Pedestrian space, bicycle speed,* and *number of meeting or passing events* on off-street pedestrian and bicycle facilities can also be of interest to analyses involving the pedestrian and bicycle modes.

MODAL INTERACTIONS

Roadways serve users of many different modes: in particular, motorists, truck operators, pedestrians, bicyclists, and transit passengers. The roadway right-of-way is allocated among the modes through the provision of facilities that ideally serve each mode's needs. However, in many urban situations, the right-of-way is constrained by adjacent land development, which causes transportation engineers and planners to consider trade-offs in allocating the right-of-way. Interactions among the modes that result from different right-of-way allocations are important to consider in analyzing a roadway, and the HCM provides tools for assessing these interactions. Local policies and design standards relating to roadway functional classifications also provide guidance on the allocation of right-of-way; safety and operational concerns should also be addressed. Exhibit 8-1 summarizes some of the key interactions that occur between modes.

Exhibit 8-1
Modal Interaction Summary

Mode Creating the Interaction	Mode Affected by the Interaction			
	Motorized Vehicle	**Pedestrian**	**Bicycle**	**Transit**
Motorized vehicle	Turning vehicles can delay other vehicles; heavy vehicles (e.g., trucks) have poorer acceleration and deceleration characteristics; traffic signal timing is influenced by relative traffic volumes on intersection approaches; intersection delay tends to increase as automobile volumes increase	Cross-street vehicle volumes influence traffic signal timing (and pedestrian delay); turning movement conflicts between vehicles and pedestrians; automobile and heavy vehicle volumes influence their perceived separation from pedestrians using sidewalks	Automobile and heavy vehicle volumes and speeds, presence of on-street parking, and the degree to which bicyclists are separated from vehicular traffic influence bicyclist comfort; turning movement conflicts with vehicles at intersections	Impacts similar to those of motorized vehicles on other motorized vehicles; buses may be delayed waiting for a gap in traffic when they leave a bus stop; day-to-day variations in traffic volumes and trip-to-trip variations in making or missing green lights affect schedule reliability
Pedestrian	Minimum green times at traffic signals may be dictated by crosswalk lengths; vehicles yield to crossing pedestrians	Cross flows where pedestrian flows intersect cause pedestrians to adjust their course and speed; pedestrian space and comfort decrease as pedestrian volumes increase	Pedestrians being met and passed by bicycles on multiuse paths affect bicyclist comfort because of pedestrians' lower speeds and tendency to walk abreast; on streets, effect on bicycles similar to that on motorized vehicles	Effects similar to those of pedestrians on motorized vehicles; transit riders are often pedestrians before and after their transit trip, so the quality of the pedestrian environment affects the perceived quality of the transit trip
Bicycle	Turning vehicles yield to bicycles; vehicles may be delayed waiting to pass bicycles in shared-lane situations	Bicycles meeting and passing pedestrians on multiuse paths affect pedestrian comfort because of the bicycles' markedly higher speeds	Bicyclists may be delayed when they pass another bicycle on-street; meeting and passing events on off-street pathways affect bicyclist comfort	Effects similar to those of bicyclists on motorized vehicles; bicycles can help extend the area served by a transit stop
Transit	Buses are heavy vehicles; buses stopping in the travel lane to serve passengers can delay other vehicles; transit signal priority measures affect the allocation of green time	Effects similar to those of motorized vehicles on pedestrians, but proportionately greater due to transit vehicles' greater size	Effects similar to those of motorized vehicles on bicyclists, but proportionately greater due to transit vehicles' greater size; transit can help extend the reach of a bicycle trip and allows a trip to be completed in the event of a flat tire or rain	Bus speeds decrease as bus volumes increase; irregular headways increase passenger loads on some buses and increase average wait times for buses

3. QUALITY AND LEVEL-OF-SERVICE CONCEPTS

OVERVIEW

There are many ways to measure the performance of a transportation facility or service—and many points of view that can be considered in making that measurement. The agency operating a roadway, automobile drivers, freight shippers, pedestrians, bicyclists, bus passengers, decision makers, and the community at large all have their own perspectives on how a roadway or service should perform and what constitutes "good" performance. As a result, there is no one right way to measure and interpret performance. The HCM provides a number of tools for describing how well a transportation facility or service operates from a traveler's perspective, a concept termed *quality of service*. One important tool for describing quality of service is the concept of LOS, which facilitates the presentation of results through the use of a familiar A (best) to F (worst) scale. A variety of specific performance measures, termed *service measures*, are used to determine LOS. These three concepts—quality of service, LOS, and service measures—are the topics of this section.

QUALITY OF SERVICE

Quality of service describes how well a transportation facility or service operates from a traveler's perspective.

Quality of service describes how well a transportation facility or service operates from a traveler's perspective. Quality of service can be assessed in a number of ways. Among them are direct observation of factors perceivable by and important to travelers (e.g., speed or delay), surveys of travelers, the tracking of complaints and compliments about roadway conditions, forecasts of traveler satisfaction on the basis of models derived from past traveler surveys, and observation of things not directly perceived by travelers (e.g., average time to clear a crash) affecting things they can perceive (e.g., speed or arrival time at work).

The HCM's focus is on the travel time, travel time reliability, speed, delay, ability to maneuver, and comfort aspects of quality of service. Other aspects of quality of service covered to a lesser degree by the HCM, or covered more thoroughly by its companion documents, include convenience of travel, safety, user cost, availability of facilities and services, roadway aesthetics, and information availability.

Dimensions of system performance and mobility.

Quality of service is one dimension of mobility and overall transportation system performance. Other dimensions to consider are the following (*4, 5*):

- *Quantity of service*—such as the number of person miles and person-hours provided by the system;
- *Capacity utilization*—including the amount of congestion experienced by users of the system, the physical length of the congested system, and the number of hours that congestion exists; and
- *Accessibility*—for example, the percentage of the populace able to complete a selected trip within a specified time.

LEVEL OF SERVICE

LOS is the stratification of quality of service.

The HCM defines LOS for most combinations of travel mode (i.e., automobile, pedestrian, bicycle, and transit) and roadway system element (e.g., freeway, urban street, intersection) addressed by HCM methodologies. Six levels are defined, ranging from A to F. LOS A represents the best operating conditions from the traveler's perspective and LOS F the worst. For cost, environmental impact, and other reasons, roadways and transit services are not typically designed to provide LOS A conditions during peak periods. Rather, a lower LOS that reflects a balance between individual travelers' desires and society's desires and financial resources is typically the goal. Nevertheless, during low-volume periods of the day, a system element may operate at LOS A.

LOS is used to translate complex numerical performance results into a simple A–F system representative of the travelers' perceptions of the quality of service provided by a facility or service. The LOS letter result hides much of the complexity of facility performance to simplify decision making about whether facility performance is generally acceptable and whether a change in this performance is likely to be perceived as significant by the general public. One of the strengths of the LOS system, and a reason for its widespread adoption by agencies, is its ability to communicate roadway performance to laypersons. However, the system has other strengths and weaknesses, described below, that both analysts and decision makers need to be mindful of.

Step Function Nature of LOS

Defining performance standards on the basis of LOS (or any fixed numerical value) means that small changes in performance can sometimes result in the standard being exceeded when a facility is already operating close to the standard.

The measure of effectiveness for automobiles at traffic signals is the average delay experienced by motorists. As traffic volumes on certain critical approaches increase, so does the average delay. The added delay may or may not result in a change in LOS. An increase of delay of 12 seconds may result in no change in LOS, a drop of one LOS letter, or a drop of two LOS letters, depending on the starting value of delay. Because there are only six possible LOS letters, each covering a range of possible values, the reported LOS does not change until the service measure increases past the threshold value for a given LOS. A change of LOS indicates that roadway performance has transitioned from one given range of traveler-perceivable conditions to another range, while no change in LOS indicates that conditions are in the same performance range as before. The service measure value—in this case, average delay—indicates more specifically where conditions lie within a particular performance range.

Because a small change in a service measure can sometimes result in a letter change in the LOS result, the LOS result may imply a more significant effect than actually occurred. This aspect of LOS can be a particularly sensitive issue when agencies define their performance standards on the basis of LOS, since a small change in performance can trigger the need for potentially costly improvements. However, this issue exists whenever a fixed standard is used, whether or not LOS is the basis of that standard.

Uncertainty and False Precision

Computer software is frequently used to perform traffic operations analyses, and software can report results to many decimal places. However, such precision is often unjustified for five reasons:

1. In contrast to the force of gravity or the flow of water through a pipe, the actions of motorists driving on a roadway can vary. Traffic operations models predict average values of performance measures; the actual value for a measure on a given day may be somewhat higher or lower. Thus, the result reported by every traffic operations model has some uncertainty associated with it.
2. A given traffic operations model may rely on the output of other models that have their own associated result uncertainties.
3. Some model inputs, such as traffic volumes, are taken to be absolute, when there is actually variation in the inputs from month to month, day to day, or even within an hour. Traffic volumes, for example, may vary by 5% to 10% from one weekday to the next.
4. Some HCM models predict traveler perceptions. Two travelers who experience identical conditions may perceive those conditions differently. When many travelers are surveyed, a distribution of responses from "very satisfied" to "very dissatisfied" (or some similar scale) results. The traveler perception models predict the average of those responses.
5. Some alternative tools involve the use of simulation, in which results will vary as inputs are randomly varied within a set distribution and average. Reporting only one result from simulation simplifies the actual results produced.

Therefore, any traffic operations performance measure value, whether resulting from an HCM methodology, simulation, or even field measurement, potentially has a fairly wide range associated with it in which the "true" value actually lies. The LOS concept helps to downplay the implied accuracy of a numeric result by presenting a range of measure results as being reasonably equivalent from a traveler's point of view. However, the same variability issues also mean that the "true" LOS value may be different from the one predicted by a methodology. One way of thinking about a reported value and its corresponding LOS is that they are the statistical "best estimators" of conditions.

LOS Reported Separately by Mode

In an effort to produce a single top-level measure of conditions, some HCM users may be tempted to blend the LOS reported for each mode into a single LOS value for a roadway element. However, each mode's travelers have different perspectives and could experience different conditions while traveling along a particular roadway. The use of a blended LOS carries the risk of overlooking quality-of-service deficiencies for nonautomobile travelers that discourage the use of those modes, particularly if the blended LOS is weighted by the number of modal travelers. Other measures, such as person delay, can be used when an analysis requires a combined measure. The HCM recommends reporting modal LOS results individually.

Neither LOS nor any other single performance measure tells the full story of roadway performance.

Reporting the Big Picture

Analysts and decision makers should always be mindful that neither LOS nor any other single performance measure tells the full story of roadway performance. Depending on the particulars of a given location and analysis, queue lengths, demand-to-capacity ratios, average travel speeds, indicators of safety, and other performance measures may be equally or even more important to consider, regardless of whether they are specifically called out in an agency standard. For this reason, the HCM provides methods for estimating a variety of useful roadway operations performance measures, and not just methods for determining LOS.

SERVICE MEASURES

Service measures are the performance measures that define LOS.

As introduced earlier, service measures are specific performance measures that are used to determine LOS. Exhibit 8-2 summarizes the service measures used by the HCM for different combinations of transportation system elements and travel modes. Some service measures are based on a traveler perception model; the components of each model are given in Exhibit 8-3.

Exhibit 8-2
Service Measures by Individual System Element

System Element	Service Measures: Motorized Vehicle	Pedestrian	Bicycle	Transit
Freeway facility	Density	--	--	--
Basic freeway segment	Density	--	--	--
Freeway weaving segment	Density	--	--	--
Ramp junction	Density	--	--	--
Multilane highway	Density	--	LOS score[a]	--
Two-lane highway	Percent time-spent-following, speed	--	LOS score[a]	--
Urban street facility	Speed	LOS score[a]	LOS score[a]	LOS score[a]
Urban street segment	Speed	LOS score[a]	LOS score[a]	LOS score[a]
Signalized intersection	Delay	LOS score[a]	LOS score[a]	--
Two-way stop	Delay	Delay	--	--
All-way stop	Delay	--	--	--
Roundabout	Delay	--	--	--
Interchange ramp terminal	Delay	--	--	--
Alternative intersection	Delay	--	--	--
Off-street pedestrian or bicycle facility	--	Space, events[b]	LOS score[a]	--

Notes: [a] See Exhibit 8-3 for the LOS score components.
[b] Events are situations where pedestrians meet bicyclists.

Exhibit 8-3
Components of Traveler Perception Models Used to Generate Service Measures

System Element	Mode	Model Components
Multilane highway and two-lane highway	Bicycle	Perceived separation between bicycles and motor vehicles, pavement quality, automobile and heavy vehicle volume and speed
Urban street facility	Motorized vehicle	Weighted average of segment motorized vehicle LOS scores
	Pedestrian	Urban street segment and signalized intersection pedestrian LOS scores
	Bicycle	Urban street segment and signalized intersection bicycle LOS scores
	Transit	Weighted average of segment transit LOS scores
Urban street segment	Motorized vehicle	Stops per mile, left-turn lane presence
	Pedestrian	Pedestrian density, sidewalk width, perceived separation between pedestrians and motor vehicles, motor vehicle volume and speed, midblock crossing difficulty
	Bicycle	Perceived separation between bicycles and motor vehicles, pavement quality, automobile and heavy vehicle volume and speed, driveway conflicts
	Transit	Service frequency, perceived speed, pedestrian LOS
Signalized intersection	Pedestrian	Street crossing delay, pedestrian exposure to turning vehicle conflicts, crossing distance
	Bicycle	Perceived separation between bicycles and motor vehicles, crossing distance
Off-street pedestrian or bicycle facility	Bicycle	Average meetings/minute, active passings/minute, path width, centerline presence, delayed passings

Note: The motorized vehicle traveler perception model for urban street segments and facilities is not used to determine LOS; however, it is provided as a performance measure to facilitate multimodal analyses.

4. ANALYSIS PROCESS

LEVELS OF HCM ANALYSIS

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

Operational Analysis

In an operational analysis, an analyst applies an HCM methodology directly and supplies all of the required input parameters from measured or forecast values. No, or minimal, default values are used. Of the available ways to apply HCM methodologies, operational analyses provide the highest level of accuracy but, as a result, also require the most detailed data collection, which has time and cost implications.

An operational analysis helps in making decisions about operating conditions. Typical alternatives consider, for example, changes in traffic signal timing and phasing, changes in lane configurations, spacing and location of bus stops, the frequency of bus service, or the addition of a bicycle lane. The analysis produces operational measures that can be used to compare the alternatives.

As discussed earlier in this chapter, even though a model's results may be highly accurate, any variability associated with the model's inputs can affect the model's results.

Planning and Preliminary Engineering Analysis

In planning and preliminary engineering analyses, an analyst applies an HCM methodology by using default values for some to nearly all of the model inputs—for example, through the use of generalized service volume tables. The results are less accurate than those of an operations analysis, but the use of default values reduces the amount of data collection and the time required to perform an analysis. In a large-scale planning study, where a large number of roadways may be evaluated, this level of analysis may be the best practical, given time and budget constraints. For future-focused studies, not all of the model inputs may be known or forecastable, which suggests the need for a planning analysis with the use of default values for the unknown model inputs.

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 statewide performance monitoring. An analyst often must estimate the future times at which the transportation system will fall below a desired LOS. Preliminary engineering analyses are often conducted to support planning decisions related to a roadway design concept and scope and in performing alternatives analyses (*5*). These studies can also assess proposed systemic policies, such as lane use control for heavy vehicles, systemwide freeway ramp metering and other intelligent transportation systems applications, and the use of demand management techniques such as congestion pricing.

Generalized Service Volume Tables

Generalized service volume tables are sometimes used in planning analyses. These tables are constructed by applying default values to an HCM methodology and then incrementally determining the maximum number of vehicles that a roadway could carry at a given LOS under the assumed conditions.

Service volume results should be applied with care, since actual conditions will likely vary in some way from the assumptions used to develop the table.

The use of a service volume table is most appropriate in situations in which evaluating every roadway or intersection within a study area is not practical. Examples of these applications would be city, county, or statewide planning studies, where the size of the study area makes conduct of a capacity or LOS analysis for every roadway segment infeasible. For these types of planning applications, the focus of the effort is simply to highlight potential problem areas (for example, locations where demand may exceed capacity or where a desired LOS may be exceeded). For such applications, a service volume table can be a useful screening tool. Once potential problem areas have been identified, more detailed analyses can be performed for those locations.

The HCM provides generalized service volume tables for

- *Freeway facilities*
- *Multilane highways*
- *Two-lane highways*
- *Urban street facilities*
- *Signalized intersections*

The characteristics of any given roadway will likely vary in some way from the assumed input values used to develop a service volume table. Therefore, the results from a service volume table should be treated as rough approximations. Service volume tables should not be substituted for other tools to make a final determination of the operational adequacy of a particular roadway.

Design Analysis

Design analyses typically apply the HCM to establish the detailed physical features that will allow a new or modified roadway 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 are seeking 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, the length of added lanes, the size of pedestrian queuing areas, the widths of sidewalks and walkways, and the presence of bus pullouts.

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

ANALYSIS TOOL SELECTION

Types of Tools

Each analytical or simulation tool, depending on the application, has its own strengths and weaknesses. It is important to relate relevant modeling features to the needs of the analysis and to determine which tool satisfies these needs to the greatest extent.

HCM methodologies are *deterministic* and *macroscopic*. A deterministic model will always produce the same result for a given set of inputs. A macroscopic model considers average conditions experienced by vehicles over a period of time (typically 15 minutes or 1 hour). In contrast, microsimulation models are *stochastic* and *microscopic*. In a stochastic model, a different random number seed will produce a different modeling result; therefore, the outcome from a simulation run based on a stochastic model cannot be predicted with certainty before the analysis begins. Microscopic models simulate the movement of individual vehicles on the basis of car-following and lane-changing theories.

Situations When Alternative Tools Might Be Considered

The HCM is the product of a large number of peer-reviewed research projects and reflects the best available techniques (at the time of publication) for determining capacity and LOS. However, the research behind the HCM has not addressed every possible situation that can arise in the real world. Therefore, the HCM documents the limitations of its procedures and highlights situations when alternative analysis tools should be considered to supplement or substitute for the HCM. The following are examples of these situations:

- The configuration of the facility has elements that are beyond the scope of the HCM procedures. Each HCM procedural chapter identifies the specific limitations of its own methodology.
- Viable alternatives being considered in the study require the application of an alternative tool to make a more informed decision.
- The performance measures are compatible with corresponding HCM measures and the decision process requires additional performance measures, such as fuel consumption and emissions, that are beyond the scope of the HCM.
- The system under study involves a group of different facilities with interactions that require the use of more than one HCM chapter. Alternative tools can analyze these facilities as a single system.
- Routing is an essential part of the problem being addressed.
- The quantity of input or output data required presents an intractable problem for the HCM procedures.
- The HCM procedures predict overcapacity conditions that last throughout a substantial part of a peak period or queues that overflow the available storage space.

The Federal Highway Administration's *Traffic Analysis Toolbox* (6) provides general guidance on the use of traffic analysis tools, including the HCM. More detailed guidance for alternative tool application to specific system elements is presented in Volumes 2 and 3 of the HCM. Supplemental examples involving situations beyond the scope of the HCM procedures are presented in Volume 4.

INTERPRETING RESULTS

Uncertainty and Variability

Model outputs—whether from the HCM or alternative tools—are estimates of the "true" values that would be observed in the field. Actual values will lie within some range of the estimated value. The size of the range, and therefore the degree of uncertainty, is a function of several variables, including the quality of the input data, the inherent variability of the model, and the degree to which the model accounts for all of the factors that may affect the results. The uncertainty may be amplified by imperfect knowledge of the traveler perception aspects of quality of service.

When simulation tools are applied, uncertainty is normally addressed by performing multiple simulation runs that use different random number seeding. Regardless of the modeling approach, a sensitivity analysis may be performed to assess the degree to which input data variation is likely to affect the range of performance results. Depending on the particular model and the specifics of the situation being modeled, small changes in model inputs can have large impacts on model outputs.

Accuracy and Precision

Accuracy and precision are independent but complementary concepts. *Accuracy* relates to achieving a correct answer, while *precision* relates to the size of the estimation range of the parameter in question. In most cases, accuracy of the field data on which the analyses are based (e.g., traffic volumes) to within 5% or 10% of the true value is the best that can be anticipated. Thus, extreme accuracy cannot be expected from the computations performed with these inputs, and the final results must be considered as estimates that are accurate and precise only within the limits of the inputs used.

Comparing HCM Results with Alternative Tools

The exact definitions of performance measures are an important issue, particularly when performance measures produced by different analysis tools are to be compared. Many tools produce performance measures with the same name (e.g., "delay"), but the definitions and methods of computation can differ widely. Chapter 7, Interpreting HCM and Alternative Tool Results, presents general guidance on comparing results. The chapters in HCM Volumes 2 and 3 present guidance on this topic for specific roadway elements.

Another source of difference in the performance measures obtained from different tools lies in their treatment of incomplete trips. Incomplete trips include those that enter a facility during a given analysis period (e.g., a 15-minute period) and exit during a subsequent period, and those that exit a facility after entering in a previous analysis period. To overcome differences among analysis tools, inclusion of an uncongested interval at all time and space boundaries of the analysis period is important.

When undercapacity operation is being studied, the definition of the facility in time and space is less important. The facility's operation tends to be more homogeneous when demand is less than capacity. For most performance measures, extending the analysis period will give a larger sample of vehicles but will not affect the performance measures significantly.

PRESENTING RESULTS

Tabular values and calculated results are displayed in a consistent manner throughout the HCM. It is suggested that analysts applying the HCM adhere to these conventions. A key objective is to present results in a way that indicates to users, decision makers, and other viewers the level of precision and accuracy associated with the results. This may require rounding results or presenting an appropriate number of digits after the decimal point, consistent with a result's expected precision and accuracy.

5. DECISION-MAKING CONSIDERATIONS

The HCM provides procedures for capacity and quality-of-service analyses and therefore serves as an analytical tool for transportation engineers and planners. However, the HCM is only a guidance document: it does not endeavor to establish a legal standard for highway design or construction. This section describes the role of other guidance and standards documents that complement the HCM, along with issues for decision makers to consider should they choose to adopt HCM service measures as standards.

ROLE OF HCM COMPANION DOCUMENTS

Throughout its history, the HCM has been a fundamental reference work for transportation engineers and planners. However, it is but one of a number of documents that play a role in the planning, design, and operation of transportation facilities and services. The HCM's scope is to provide tools to evaluate the performance of highway and street facilities in terms of operational and traveler perception measures. This section describes companion documents to the HCM that cover important topics outside the HCM's scope.

Highway Safety Manual

The *Highway Safety Manual* (HSM) (*7*) provides analytical tools and techniques for quantifying the safety effects of decisions related to planning, design, operations, and maintenance. The information in the HSM is provided to assist agencies as they integrate safety into their decision-making processes. It is a nationally used resource document intended to help transportation professionals conduct safety analyses in a technically sound and consistent manner, thereby improving decisions made on the basis of safety performance.

A Policy on Geometric Design of Highways and Streets

The American Association of State Highway and Transportation Officials' (AASHTO's) *A Policy on Geometric Design of Highways and Streets* ("Green Book") (*8*) provides design guidelines for roadways ranging from local streets to freeways, in both urban and rural locations. The guidelines "are intended to provide operational efficiency, comfort, safety, and convenience for the motorist," while also emphasizing the need to consider the use of roadway facilities by other modes.

Manual on Uniform Traffic Control Devices

The Federal Highway Administration's *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*9*) is the national standard for traffic control devices for any street, highway, or bicycle trail open to public travel. Of particular interest to HCM users are the sections of the MUTCD pertaining to warrants for all-way STOP control and traffic signal control, signing and markings to designate lanes at intersections, and associated considerations of adequate roadway capacity and less restrictive intersection treatments.

Transit Capacity and Quality of Service Manual

The *Transit Capacity and Quality of Service Manual* (TCQSM) (*10*) is the transit counterpart to the HCM. The TCQSM contains information on the various types of public transportation and their capacities and provides a framework for measuring transit service from the passenger point of view.

Traffic Analysis Toolbox

At the time of writing, the Federal Highway Administration had produced 14 volumes of the *Traffic Analysis Toolbox* (6), providing guidance on the selection and deployment of a range of traffic analysis tools, including the HCM.

USE OF THE HCM IN DECISION MAKING

Although the HCM does not set standards—for example, it does not specify a particular LOS that should be provided for a particular roadway type—it is referenced in the AASHTO Green Book (*8*), and numerous agencies and jurisdictions have adopted LOS standards based on the HCM. This section discusses issues that agencies and jurisdictions should consider when they apply HCM methods, set operations standards based on the HCM, or both.

Impact of Changes in HCM Methods

Each new edition of the HCM incorporates new methodologies and—in some cases—new service measures for evaluating roadway system elements. This edition of the HCM is no different. Sometimes, new methods are added to address emerging types of system elements (e.g., roundabouts, managed lanes, alternative intersections), to assess roadway performance in new ways (e.g., travel time reliability), or to address new paradigms (e.g., designing and operating roadways to serve multiple travel modes). In other cases, methods are updated to improve estimates of service and other performance measures. These changes can affect transportation agencies that apply the HCM:

- *New methods* provide additional tools for transportation agencies to use in planning and operating their roadway network.
- *Changes in methodologies* are designed to provide better estimates of performance than the previous version of the method, on the basis of new research. Because the underlying methodology has changed, the estimated performance of a roadway can change as a result of applying the new method, even though nothing about the roadway itself has changed. These changes can result in the need for new projects to address the newly identified deficiencies, as well as the possibility that previously identified projects are no longer needed.
- *Changes in service measures or LOS thresholds* are intended to reflect more closely the traveler's perspective of roadway operations. In these cases, agencies that have adopted operations standards using such measures are encouraged to reconsider their standards to ensure that they still represent the quality of service the agency wishes to provide. These kinds of changes in the HCM may also have planning and project programming implications, since the need for or scale of a given project may change.

- *Changes in HCM default values* may cause analysis results to differ from one version of the HCM to the next, since some of the input data provided to a method have changed even though the underlying method has not. Following the HCM's recommendations of using field-measured input values whenever possible and locally generated default values otherwise avoids this issue.

Incorporating HCM Analysis Results into Decision Making

Agencies and jurisdictions adopt roadway design and operations standards for a number of reasons, including consistency in roadway design across a jurisdiction and provision of an objective basis for making decisions on required improvements. As mentioned earlier, numerous agencies and jurisdictions have chosen to adopt LOS standards for their roadways. The existence of computerized tools that implement HCM procedures makes it easy for analysts to test a number of roadway improvements against a LOS standard. However, the analysis does not end once a LOS result has been determined.

The existence of a LOS F condition does not, by itself, indicate that action must be taken to correct the condition. Conversely, meeting a LOS standard does not necessarily mean that no problem exists or that an improvement that produces the desired LOS is a desirable solution. Other issues, including but not limited to safety, impacts on other modes, traffic signal warrants, turn-lane warrants, cost–benefit issues, and access management, may also need to be considered as part of the analysis, recommendations, and eventual decision. As always, engineering judgment should be applied to any recommendations resulting from HCM (or alternative tool) analyses.

Two examples of common situations where a LOS result considered by itself might lead to a decision different from one that would be reached if other factors were also considered are given below.

Traffic Signal Warrants

The MUTCD (*9*) provides a number of warrants that indicate when a traffic signal may be justified. It is possible to have a condition at a two-way STOP intersection—particularly when a low-volume minor street intersects a high-volume major street—where the minor street approach operates at LOS F but does not meet traffic signal warrants. Because the MUTCD is the standard for determining when a traffic signal is warranted, a LOS F condition by itself is not sufficient justification for installing a signal.

Turn-Lane Warrants

A number of agencies and jurisdictions have adopted warrants that indicate when the installation of turn lanes may be justified at an intersection. It is possible for an HCM analysis to indicate that the addition of a turn lane will result in an acceptable LOS but for the turn-lane warrant analysis to determine that the necessary conditions for installing a turn lane have not been satisfied. In this case, the potential for a satisfactory LOS in the future would not be sufficient justification by itself for installing the turn lane.

6. REFERENCES

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